# Nuclear Criticality Safety Assessment of Waste Evaluation and Assay Activities at the Hematite Site

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## Revision History

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Glossary of Acronyms, Abbreviations, and Terms

| Acronym/Term | Definition |
|---|---|
| ' | Foot (12") |
| " | Inch (2.54 cm) |
| ACM | Asbestos Containing Material |
| AEC | Atomic Energy Commission |
| ALARA | As Low As Reasonably Achievable |
| Assay Containers | Containers presented for radiological characterization at a MAA and which comprise exhumed *fissile material*, suspect *fissile material* or the material content of exhumed intact containers. |
| Bq | One radioactive disintegration per second |
| BWCSR | Buried Waste and Contaminated Soil Remediation |
| cc | Cubic centimeter |
| CCIS | Criticality Control Inventory System |
| CD | Collared Drums (CDs) are used for *Field Container*, *Assay Container* or *Fissile Material Container* transit between functional areas of the site, and for *Field Container*, *Assay Container* or *Fissile Material Container* staging/storage. Each CD has a cylindrical geometry, possessing a minimum internal diameter of 57cm.<br><br>Each CD, irrespective of dimension, is fitted with a collar that extends 18" beyond the external radial surface of the CD. The CD collar is designed to ensure that any un-stacked arrangement of CDs would guarantee a minimum 36" separation distance between the outer surfaces of the CDs. The affixed collar is permanently secured to the CD and is not removed at any time the CD is being used, except when secured in a FMSA or CDRA. |
| CDBS | Collared Drum Buffer Store – area used to interim store *Field Containers* and *Assay Containers* that do not have assigned $^{235}U$ mass contents and are loaded in sealed CDs. |
| CDRA | Collared Drum Repack Area - area used to repackage or batch the contents of CDs to allow consolidation of CDs. |
| CDSA | Collared Drum Staging Area – area used to stage *Field Containers* (loaded in sealed CDs) that have been generated from site remediation activities and are believed to have the potential to contain SNM in a quantity/concentration sufficient to require NCS controls/oversight. |
| CFR | Code of Federal Regulations |
| Ci | Curie (equivalent to $3.7 \times 10^{10}$ Bq) |
| cm | Centimeter |
| cpm | Counts per minute |
| CSC | Criticality Safety Control |
| Cut Depth | Maximum permitted thickness of a layer of buried wastes/contaminated soils that is permitted to be exhumed following implementation of in-situ radiological survey and visual inspection procedures and removal of fissile items and the other items noted in the *Field Container* definition. |
| DCGL | Derived Concentration Guideline Levels |
| DCP | Double Contingency Principle |

| | |
|---|---|
| D&D | Decontamination and Decommissioning |
| DinD | Defense-in-Depth |
| Field Containers | Containers comprising exhumed *fissile material*, suspect *fissile material*, and:<br>• items that resemble intact containers;<br>• bulky objects with linear dimensions exceeding the permitted *cut depth*; and<br>• any other items with properties that are not consistent with the calibration basis of the in-situ radiological survey equipment (e.g., large metallic or dense items). |
| Fissile Material Containers | Containers comprising material with an established $^{235}U$ gram content. |
| Fissile Material | Material containing fissile nuclides (e.g., $^{235}U$) in a quantity/concentration sufficient to require NCS controls/oversight. |
| FMSA | Fissile Material Storage Area – area used to interim store *Fissile Material Containers* that have an ascribed $^{235}U$ mass content. The *Fissile Material Containers* are sealed within CDs. |
| FSS | Final Status Survey |
| g | Gram |
| gallon | 3.785 L |
| GUNFC | Gulf United Nuclear Fuels Corporation |
| HDP | Hematite Decommissioning Project |
| HEU | Highly Enriched Uranium |
| HPT | Health Physics Technician |
| HRGS | High Resolution Gamma Spectrometer |
| keV | Kilo Electron Volt |
| kg | Kilogram |
| L | Liter |
| LLW | Low Level Waste |
| $\mu$ | Micro ($1.0 \times 10^{-6}$) |
| m | Meter |
| MAA | Material Assay Area - area used to assay exhumed *fissile material*, suspect *fissile material* or the material content of exhumed intact containers, in order to provide a $^{235}U$ gram inventory estimate. |
| MARSSIM | Multi Agency Radiation Survey and Site Investigation Manual |
| MC&A | Material Control and Accountability |
| mg | Milligram |
| NCS | Nuclear Criticality Safety |
| NCSA | Nuclear Criticality Safety Assessment |
| NCS Exempt Material | Material containing an insufficient quantity/concentration of fissile nuclides (e.g., $^{235}U$) to require NCS controls/oversight |
| p | Pico ($1.0 \times 10^{-12}$) |
| PCE | Perchloroethylene |

| | |
|---|---|
| Survey Area | Clearly delineated area of land subject to in-situ radiological survey, and for which excavation activities are planned. |
| SNM | Special Nuclear Material - material containing fissile nuclides (e.g., $^{235}U$) |
| SSC | System, Structure and Component |
| TCE | Trichloroethene |
| U | Uranium |
| UNC | United Nuclear Corporation |
| vol. % | Percentage by volume |
| Waste Container | Containers used to hold materials classified as *NCS Exempt Material* following operations in a WEA and/or MAA. |
| WHA | Waste Holding Area – area used to stage solid wastes generated from site remediation activities that have been categorized as *NCS Exempt Material.* |
| WEA | Waste Evaluation Area – area used to evaluate solid wastes generated from site remediation activities that are believed to have the potential to contain SNM in a quantity/concentration sufficient to require NCS controls/oversight. |
| WTS | Water Treatment System |
| wt. % | Percentage by weight |
| yd | Yard (36") |

# 1.0 INTRODUCTION

This Nuclear Criticality Safety Assessment (NCSA) is provided to support final decommissioning of the Hematite site. The operations assessed in this NCSA encompass waste evaluation and assay activities. The results of this NCSA will be applied to all Waste Evaluation Areas (WEAs) and Material Assay Areas (MAAs) used in support of Hematite Decommissioning Project (HDP) remediation operations.

This NCSA is organized as follows:

- **Section 1** introduces the NCSA of waste evaluation and assay activities at the Hematite site and provides an overview of the operations to be performed.
- **Section 2** provides the risk assessment of the waste evaluation and assay activities outlined in Section 1.
- **Section 3** summarizes the important facility design features, equipment and procedural requirements identified in the criticality safety risk assessment provided in Section 2.
- **Section 4** details the conclusions of the NCSA of waste evaluation and assay activities at the Hematite site.

## 1.1 Description of the Hematite Site

The Westinghouse Hematite site, located near Festus, MO, is a former nuclear fuel cycle facility that is currently undergoing decommissioning. The Hematite site consists of approximately 228 acres, although operations at the site were confined to the "central tract" area which spans approximately 19 acres. The remaining 209 acres, which is not believed to be radiologically contaminated, is predominantly pasture or woodland.

The central tract area is bounded by State Road P to the north, the northeast site creek to the east, the union-pacific railroad tracks to the south, and the site creek/pond to the west. The central tract area currently includes former process buildings, facility administrative buildings, a documented 10 CFR 20.304 burial area, two evaporation ponds, a site pond, storm drains, sewage lines with a corresponding drain field, and several locations comprising contaminated limestone fill.

## 1.2 Hematite Site History

Throughout its history, operations at the Hematite facility included the manufacturing of uranium metal and compounds from natural and enriched uranium for use as nuclear fuel. Specifically, operations included the conversion of uranium hexafluoride ($UF_6$) gas of various $^{235}U$ enrichments to uranium oxide, uranium carbide, uranium dioxide pellets, and uranium metal. These products were manufactured for use by the federal government and government contractors and by commercial and research reactors approved by the Atomic Energy Commission (AEC). Research and Development was also conducted at the facility, as were uranium scrap recovery processes.

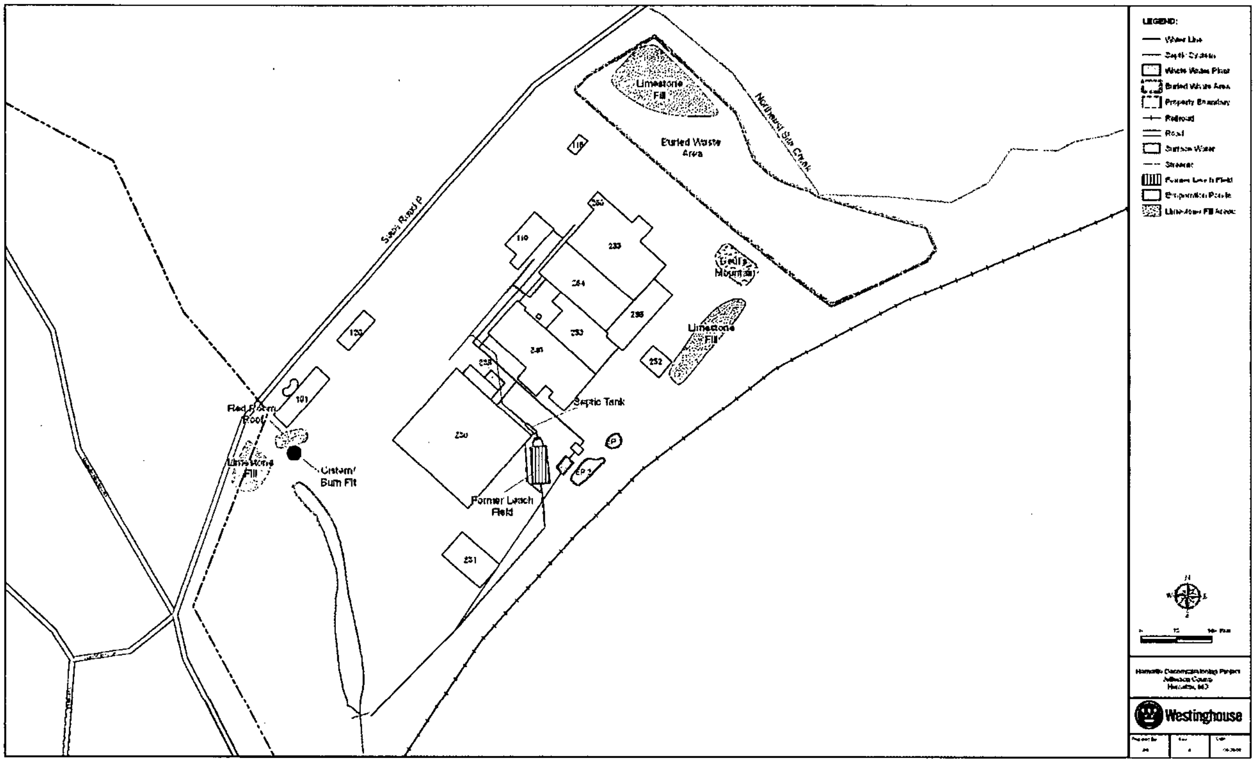
The Hematite facility was used for the manufacture of low-enriched ( i.e., $\leq$ 5.0 wt.% $^{235}U$), intermediate-enriched (i.e., >5 wt.% and up to 20 wt.% $^{235}U$) and high-enriched (i.e., > 20 wt.% $^{235}U$) materials during the period 1956 through 1974. In 1974 production of intermediate and high-enriched material was discontinued and all associated materials and equipment were removed from the facility. From 1974 to cessation of manufacturing operations in 2001, the Hematite facility produced nuclear fuel assemblies for commercial nuclear power plants. In 2001, fuel manufacturing operations were terminated and the facility license was amended to reflect a decommissioning scope. Accountable uranium inventory was removed and Decontamination and Decommissioning (D&D) of equipment and surfaces within the process buildings was undertaken. This effort resulted in the removal of the majority of process piping and equipment from the buildings. At the conclusion of that project phase, the accessible surfaces of the remaining equipment and surfaces of the buildings were sprayed with fixative in preparation for building demolition.

### 1.2.1 Historic Operations

Historic operations at the Hematite site resulted in the generation of a large volume of process wastes contaminated with uranium of varying enrichment. Records indicate that as early as 1958, facility process wastes were consigned to unlined burial pits situated in the North East corner of the sites central tract.

#### 1.2.1.1 Documented Process Waste Burials

Based on historic documentation (Ref. 6), 40 unlined pits were excavated northeast of the plant buildings and southwest of "Northeast Site Creek" and were used for the disposal of contaminated materials generated by fuel fabrication processes at Hematite between 1965 and 1970. The documented burial area perimeter is outlined in Figure 1-1. Based on best available information, it is believed that the burial pits are nominally 20' × 40' and 12' deep.




Source: Ref. 6

Figure 1-1 Documented Burial Pit Area

Consignment of waste to the burial pits was reported to be in compliance with AEC regulation 10 CFR 20.304 (1964; Ref. 7). Facility operating procedures (Ref. 8) described the size and spacing requirement for the burial pits, in addition to the required thickness of the overlying soil cover (4'), and the quantity of radioactive material that could be buried in each pit. The procedures in place at the time of operation of the burial pits required that buried waste be covered with approximately 4' of soil following completion of pit filling operations. However, it is possible that the soil cover thickness may have been modified over time as the area where the burial pits are located was re-graded on several occasions.

United Nuclear Corporation (UNC) and Gulf United Nuclear Fuels Corporation (GUNFC) maintained detailed logs of burials for the period of July of 1965 through November of 1970. The Burial Pit log books (Ref. 9) contain approximately 15,000 data entries listing the date of burial, pit number, a description of the particular waste consignment, the uranium mass associated with the subject waste and miscellaneous logging codes. Some logbook entries also list percent enrichment for the uranium. On-site burial of radioactive material ceased in November of 1970.

The information recorded in the Burial Pit log books indicates that the waste consignments comprised a wide variety of waste types. This is further supported by interviews with past employees (Ref. 10). A listing of the types of waste materials that may be present in the Burial Pits is provided in Table 1-1. The primary waste types expected to be encountered are trash, empty bottles, floor tile, rags, drums, bottles, glass wool, lab glassware, acid insolubles, and filters. Buried chemical wastes include hydrochloric acid, hydrofluoric acid, potassium hydroxide, trichloroethene (TCE), perchloroethylene (PCE), alcohols, oils, and waste water.

Table 1-1 Buried Waste Characteristics

| Process Metals and Metal Wastes | |
|---|---|
| • High enriched uranium (93-98%)<br>• Depleted and natural uranium<br>• Beryllia $UO_2$<br>• Beryllium plates<br>• Uranium-aluminum<br>• Uranium-zirconium<br>• Thorium $UO_2$ | • $UO_2$ samarium oxide<br>• $UO_2$ gadolinium<br>• Molybdenum<br>• Uranium dicarbide<br>• Cuno filter scrap that included beryllium oxide<br>• Niobium pentachloride |
| **Chemical Wastes** | |
| • Chlorinated solvents, cleaners and residues (perchloroethylene, trichloroethylene)<br>• Acids and acid residues<br>• Potassium hydroxide (KOH) insoluables<br>• Ammonium nitrate<br>• Oxidyne<br>• Ethylene glycol | • Ammonium bichloride<br>• Sulfuric acid<br>• Uranyl sulfate<br>• Acetone<br>• Methyl-alcohol<br>• Chlorafine<br>• Pickling solution<br>• Liquid organics |
| **Other Wastes** | |
| • Tiles from Red Room floor<br>• Process equipment waste oils<br>• Oily rags<br>• TCE/PCE rags<br>• Used sample bottles<br>• Green salt ($UF_4$)<br>• Calcium metal | • Contaminated limestone<br>• $UO_2$ $THO_2$ Paper Towels<br>• Pentachloride from vaporizer<br>• Used Magnorite<br>• $NbCl_5$ vaporizer Cleanout<br>• Item 51 Poison equipment<br>• Asbestos and Asbestos Containing Material (ACM) |

Source: Adapted from Ref. 6

The recorded (Ref. 9) total uranium mass associated with the waste consignments range from 178 g$^{235}$U to 802 g$^{235}$U per burial pit with a maximum amount associated with any single waste consignment (i.e., burial item) of 44 g$^{235}$U. The uranium enrichment of waste items consigned to the burial pits ranged from 1.65 wt. % to 97.0 wt. % $^{235}$U/U. According to the Burial Pit log books, the five most frequent waste consignments comprised:

- Acid insolubles (2,050 entries);
- Glass wool (2,080 entries);
- Gloves and liners (900 entries);

- Red Room trash (570 entries); and
- Lab trash (515 entries).

The waste consignments representing the highest recorded $^{235}U$ content included:

- Wood filters (4 entries ranging from 22 to 44 g$^{235}$U);
- Metal shavings (one entry at 41 g$^{235}$U);
- Leco crucibles (4 entries ranging from 29-31.6 g$^{235}$U); and
- Reactor tray (one entry at 40.4 g$^{235}$U).

#### 1.2.1.2 Undocumented Burials

It is assumed (Ref. 6) that additional undocumented burial pits may exist within the area between the former process buildings and the documented burial pit area. Based on interviews with former site employees (Ref. 10), it is possible that on-site burials other than burials conducted under 10CFR20.304 (1964; Ref. 7) may have occurred as early as 1958 or 1959. Specifically, three or four burials may have been performed each year prior to 1965 for disposal of general trash and items that were lightly contaminated by then current radiological free release standards (Ref. 5). Based on this information, it is estimated that a total of 20-25 burial pits may exist for which there are no records. Waste consignments to these burial pits (i.e., prior to 1965) were not documented (logged) as they were not considered to contain significant quantities of Special Nuclear Material (SNM) (Ref. 11). No specific information has been found to indicate the explicit nature of the waste consignments associated with these undocumented burials.

#### 1.2.1.3 Other Burials

##### 1.2.1.3.1 Red Room Roof Burial Area

The Building 240 Red Room roof burial area is described in Reference 5. The Building 240 Red Room roof was replaced during the mid 1980s. The removed roofing materials were buried on site near Building 101 - the Tile Barn. The Red Room roof burial area has the potential to contain residual radioactivity in excess of natural background due to the high enriched processes that took place within the Red Room from 1956 through 1973. However, since only roofing materials were known to be consigned to this burial area, it is believed that the potential to encounter any significant residual uranium is very small.

##### 1.2.1.3.2 Cistern Burn Pit Area

The cistern burn pit area southwest of Building 101, the Tile Barn, was used to burn wood pallets that may have contained some level of contamination. Therefore, this area may include residual radioactivity in excess of natural background.

### 1.2.2 Current State

The burial pits are currently in a quiescent state, although the pits may have been subjected to disturbances in the past and have been subjected to characterization sampling initiatives (Ref. 1).

The results of sampling campaigns indicate a maximum $^{235}U$ concentration of 53.5 pCi/g, corresponding to a $^{235}U$ concentration of approximately 2.5 μg/g(waste matrix). Based on the sample data and the original burial logs, the burial pits are believed to contain only small quantities of $^{235}U$ (i.e., less than 1 kg $^{235}U$ per burial pit).

During 2008 an extensive site sampling and survey program was implemented. The site-wide survey included sampling of soils within the burial pit area, the gas line, the leach field, and land areas adjacent to the process buildings. The burial pit area sampling activities were focused on providing better understanding of the location of the individual burial pits, associated overburden, depth and nature of buried wastes, and contamination levels immediately beneath the individual pits. The other sampling activities were focused on soils surrounding the natural gas line that runs adjacent to the burial pit area and soils around the former process buildings. In addition, samples were extracted from the leach field to complement previous sampling efforts. A breakdown of the sampling program is provided in Table 1-2.

Table 1-2 2008 Sampling Program Breakdown

| Area | Number of Cores | Maximum Core Depth (ft) |
|---|---|---|
| Burial Pit | 73# | 16# |
| Gas Line | 4 | 16 |
| | 7 | 16 |
| | 8 | 10 |
| | 8 | 10 |
| | 10 | ~5 |
| | 3 | 5-6 |
| Leach Field | 5 | 10 |
| Adjacent Soils | 28 | 10 |
| Total | 146 | |

Source: Ref. 5

Notes: # Three (3) of the burial pit sample locations were used for water drawdown well construction and measured ~30' in depth.

In total, 146 sample cores were exhumed across the site, seventy-three (73) of which were exhumed from the area of land occupied by the documented burial pits. The field activities included surface sampling with shovels and scoops, auguring by hand, and advancement of soil borings using hollow stem augers equipped with split spoon samplers. Each exhumed soil core was screened in the field using instruments to detect radiological and chemical contaminants, including the presence of $^{235}U$.

Analysis of all of the sample cores exhumed from the burial areas of the site revealed a maximum $^{235}U$ concentration of 153 pCi/g, equivalent to 0.11 g$^{235}$U/L*.

### 1.3 Overview of the Site Remediation Objectives

The site remediation objectives relevant to buried waste exhumation and contaminated soil remediation are described below. These site-wide remediation objectives are applicable to all HDP remediation areas. These are relevant to WEA and MAA operations because under certain circumstances (described in Section 1.4), the materials exhumed from these areas may be transferred to a WEA/MAA for evaluation/assay.

HDP remediation areas will be excavated to a depth where historical knowledge, and/or visible and radiological evidence indicate that buried wastes, radiological contaminants and chemical contaminants of concern have been removed. Once these objectives are met, Final Status Survey (FSS) and hazardous material remediation goals can be verified. FSS goals are based on area and depth specific Derived Concentration Guideline Levels (DCGL). Verification of FSS goals is accomplished by a combination of in-situ radiological surveys and sample extraction and analyses. Verification of hazardous material remediation goals is accomplished by a combination of direct measurements and sample extraction and analyses. In all cases, excavation activities in HDP remediation areas will be conducted in accordance with the governing NCSA requirements until the FSS and hazardous material remediation goals are achieved and verified.

Following verification that FSS and hazardous material remediation goals have been achieved, the subject HDP remediation areas may be declared 'remediated', allowing initiation of site restoration activities such as backfilling and grading.

* Conversion of pCi/g to g$^{235}$U/L concentration:

Specific activity of $^{235}U = 2.16107\times10^{-6}$ Ci/g$^{235}$U = $2.16107\times10^{6}$ pCi/g$^{235}$U,

$$\frac{153\ pCi/g(sample)}{2.16107\times10^{6}\ pCi/g^{235}U} = 7.08\times10^{-5}\ g^{235}U/g(sample),$$

$$7.08\times10^{-5}\ g^{235}U/g(sample)\times1.6\ g(sample)/cc = 0.11\ mg^{235}U/cc = 0.11\ g^{235}U/L$$

## 1.4 Overview of HDP Operations

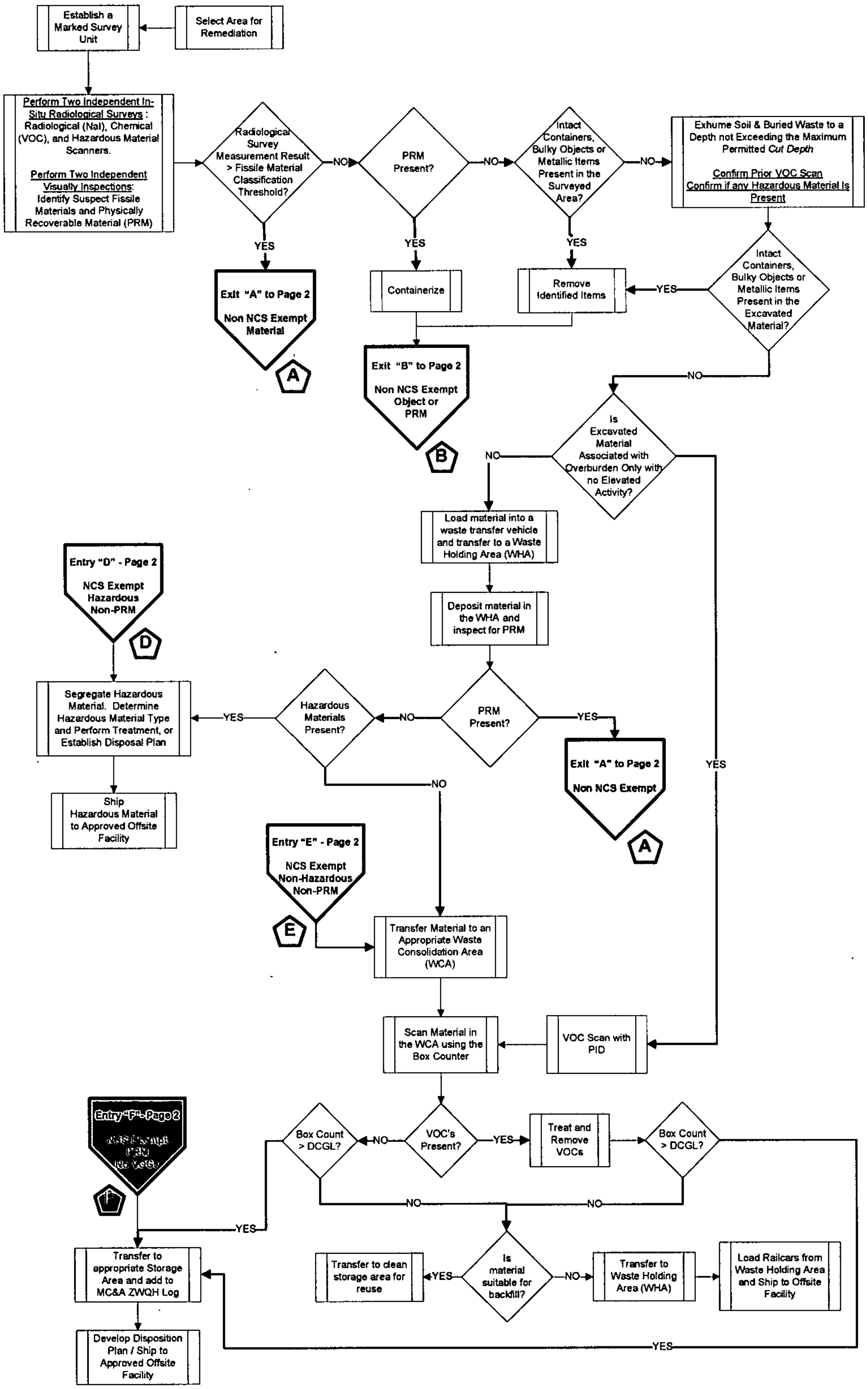
This Section provides an overview of HDP operations. The process presented is the result of an iterative engineering assessment that has received input from engineers, safety personnel and operators knowledgeable in the process. This section provides only a criticality overview of operations and is not intended to provide an exhaustive or comprehensive process description.

A simplified schematic of the key HDP operations are encompassed within the flowcharts presented in Figure 1-2 and Figure 1-3. The flowcharts illustrate the basic process that will be followed and provide an indication of material flow paths throughout the entire process. The information presented in the flow charts is highly generalized and should not be misconstrued as representing formal controls.

The buried waste and contaminated soil remediation processes presented in Figure 1-2 and Figure 1-3 encompass a range of 'functional areas' where operations are performed. The functional areas of interest from a Nuclear Criticality Safety (NCS) perspective are areas where *fissile materials* may be recovered, containerized, staged, evaluated, packaged, characterized or interim stored. These functional areas comprise:

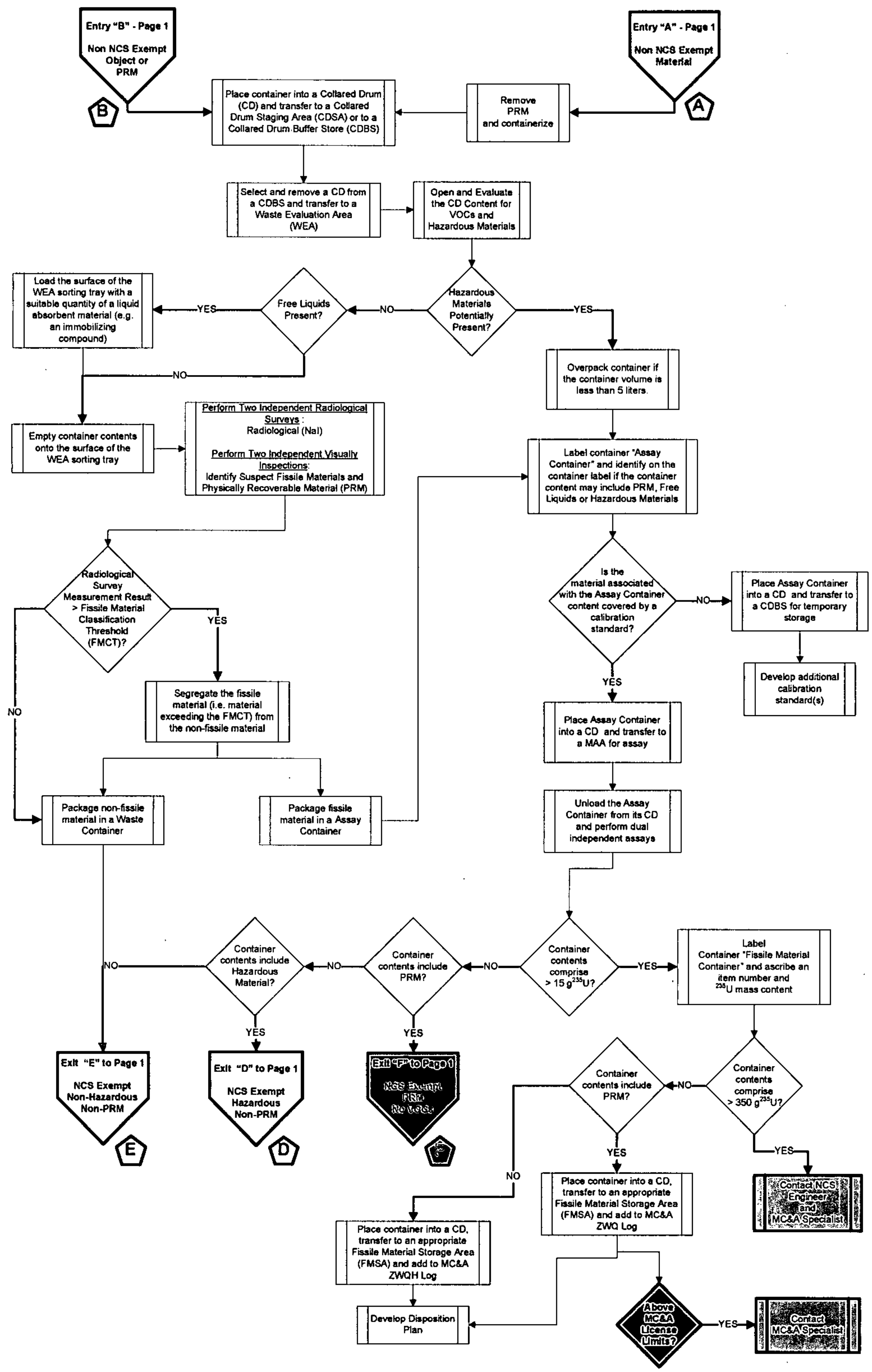
1) Land areas being remediated (i.e., the areas occupied by burial wastes and contaminated soils);
2) Collared Drum Staging Area(s) (CDSAs);
3) Collared Drum Buffer Store(s) (CDBSs)
4) Waste Evaluation Area(s) (WEAs);
5) Material Assay Area(s) (MAAs);
6) Collared Drum Repack Area(s) (CDRAs); and
7) Fissile Material Storage Area(s) (FMSAs).

An overview of operations in each of the abovementioned functional areas is provided in the following sub-sections to orient the reader. The functional areas addressed in this NCSA concern WEAs and MAAs. These areas are discussed in Sections 1.4.4 and 1.4.5.




Source: Original

Figure 1-2 Simplified Schematic of Buried Waste Exhumation and Contaminated Soil Remediation – PAGE 1: Excavation, Waste Management, and Disposition




Source: Original

Figure 1-3 Simplified Schematic of Buried Waste Exhumation and Contaminated Soil Remediation – PAGE 2: Fissile Material Extraction, Containerization, Staging, Evaluation, Assay, Handling, and Storage

### 1.4.1 Buried Waste and Contaminated Soil Areas

A simplified schematic of the buried waste and contaminated soil exhumation processes is provided in Figure 1-2 and Figure 1-3.

Prior to removal of soil/waste from a remediation area of the Hematite site, comprehensive in-situ radiological survey and visual inspection of a clearly defined survey area (i.e., the area to be exhumed) is undertaken to identify potential item(s) or region(s) containing *fissile material.*

The in-situ radiological survey will typically use NaI scintillator probes to provide gamma ray measurements of the surface area of interest. The survey technique that may be routinely performed is the Multi Agency Radiation Survey and Site Investigation Manual (MARSSIM) protocol which involves walking straight parallel lines over an area while moving the detector in a serpentine motion, 2 inches to 4 inches above the surface. Employing the MARSSIM protocol provides a high degree of assurance that all areas will be properly characterized prior to exhumation. Other in-situ radiological survey equipment and survey techniques may be employed provided that they meet procedural requirements. Other radiological survey equipment may include, but is not limited to, the use of High Resolution Gamma Spectrometers (HRGS). Examples of other survey techniques may include, but is not limited to, the use of motorized equipment.

The objective of the in-situ radiological surveys is to identify any item or region of soil/waste with a fissile concentration exceeding 1 g$^{235}$U in any contiguous 10 liter volume. The 1 g$^{235}$U/10L threshold provides a high degree of assurance that any items with elevated (i.e., non-trivial) levels of $^{235}$U contamination would be identified. The in-situ radiological surveys are complemented by visual inspection of the survey area with the aim of identifying:

1) any items with the potential to contain *fissile material* (e.g., a process filter);
2) items that resemble intact containers;
3) bulky objects with linear dimensions exceeding the permitted *cut depth*; and
4) metallic items*.

Any item(s) or region(s) containing, or potentially containing, *fissile material* (identified from the results of the radiological survey and visual inspection) are carefully removed, loaded into a *Field Container* and placed inside a sealed Collared Drum (CD)†. Loaded CDs are transferred to a CDSA for staging, a CDBS for interim storage, an available WEA for evaluation, or to an available MAA for characterization. The remaining portion(s) of the surveyed area, to a depth not exceeding the maximum permitted *cut depth* represents material not of interest from a NCS perspective. These *NCS exempt materials* are exhumed and transferred to a suitable material stockpile in a

* The concern with metallic items is that their properties may not be consistent with the calibration basis of the in-situ radiological survey equipment. For example, their high atomic number and/or density could provide more photon attenuation than accounted for in the calibration basis of the in-situ radiological survey equipment.

† Refer to Section 1.5.6 for a description of CDs.

Waste Holding Area (WHA)*.

An exception to the above process occurs in the event objects meeting criteria (2), (3) or (4) above are encountered. This is because their exhumation could constitute the removal of material with a depth exceeding the maximum permitted *cut depth*, and/or their content could comprise dense and/or high atomic number material (e.g., items or fragments constructed of steel), which could provide more attenuation than accounted for in the in-situ radiological survey equipment calibration basis. For this reason, objects meeting these criteria are extracted and treated equivalently to item(s) or region(s) known to contain *fissile material* (from the results of the in-situ radiological surveys), as described above.

### 1.4.2 Collared Drum Staging Area(s)

Depending on the generation rate of *Field Containers* during remediation work it may be operationally advantageous to stage CDs loaded with *Field Containers* in a protected area local to the excavation site(s). Each CDSA will comprise a clearly delineated area that have an even and level terrain and is protected against accident disturbance (e.g., impact from moving excavation equipment or waste transfer vehicles) by a robust physical barrier (e.g., concrete barricades similar to the type used to provide median barriers for road traffic). Due to material security and shelter requirements (i.e., shelter from precipitation and the environment) all CDs staged in a CDSA during an operation shift are removed and placed into a CDBS prior to completion of the operations shift.

### 1.4.3 Collared Drum Buffer Store(s)

Depending on the generation rate of *Field Containers* during remediation work and the availability of WEAs and MAA(s), it may be necessary to interim store CDs loaded with *Field Containers* in a CDBS. CDBSs may also be used for interim storage of any other CDs loaded with containers with un-assigned fissile mass content. For example, CDs loaded with *Assay Containers* may be stored on an interim basis in a CDBS in the event that a MAA is not available or if the approved calibration algorithms available at a MAA are not valid due to the material properties of the *Assay Container* content.

Each CDBS will be established within an enclosed structure to protect the CDs within their environs against accident disturbance and to afford access control and shelter from precipitation and the environment.

### 1.4.4 Waste Evaluation Area(s)

Each WEA is equipped with one sorting tray and gamma survey instrument(s) and is bounded by a clearly defined perimeter. A simplified schematic of the WEA operations is provided in Figure 1-3.

All *fissile materials*, suspect *fissile materials*, items resembling intact containers, bulky objects and

* An overview of WHA operations is not provided in this NCSA because operations in WHAs are not subject to NCS controls or oversight. WHAs are used to stage and accumulate exhumed wastes and impacted soils in preparation for waste consolidation and shipment from the site in large gondola rail cars.

metallic items identified during operations in a HDP remediation area will be containerized (individually) in CDs and ultimately transferred to a WEA for evaluation of fissile content. In addition, solids recovered from the site Water Treatment System (WTS) will be containerized in CDs and may be transferred to a WEA for evaluation of fissile content.

Following WEA operations, *fissile materials* are transferred to a MAA for radiological counting to establish $^{235}U$ mass content*. The general aim of waste evaluation operations is to identify and extract uranium associated with the material content of an incoming CD that would be of concern from a NCS perspective. Identification of uranium is achieved by spreading/disassembling the material content of the CD across the surface of a sorting tray, and using hand-held gamma survey instruments and visual inspection to locate the uranium.

The waste evaluation process (conducted at a WEA) is summarized below:

1) A CD loaded with either a *Field Container,* any item resembling an intact container, a bulky object or a metallic item is received and accepted in a WEA;
2) The content of the CD is removed and transferred to the WEA sorting tray;
3) If the CD content comprised a *Field Container* or an item resembling an exhumed intact container then the container is opened and an approved volume of its content is tipped onto the surface of the WEA sorting tray;
4) The material tipped onto the surface of the sorting tray is spread across the surface of the tray. If the CD content comprised a bulky object or metallic item the items are disassembled to permit evaluation of any interior void spaces;
5) The spread/disassembled material is visually inspected and radiologically surveyed using hand-held gamma counters to locate uranium;
6) Any item or region of the spread/disassembled material that has a fissile concentration exceeding 1 g$^{235}U$ in any contiguous 10 liter volume is identified, collected, and placed in an *Assay Container*;
7) When all material exceeding the 1 g$^{235}U$/10L concentration threshold has been identified and placed into the *Assay Container*, the *Assay Container* is lidded and transferred to a MAA for radiological assay. The remaining portions of the spread/disassembled material (i.e., the residual potion not containing any significant uranium) is gathered and loaded into a *Waste Container*; and
8) The *Waste Container* is removed from the WEA and dispositioned as *NCS Exempt Material* (i.e., transferred to a WHA).

### 1.4.5 Material Assay Area(s)

Each MAA will comprise a clearly delineated and sheltered area equipped with assay equipment.

* Note that in some instances, the content of a CD may not actually be 'evaluated' in a WEA (e.g., due to the potential for hazardous material content). These CDs may be transferred directly to a MAA for assay. Also note that CDs may be buffer stored in a CDBS at any time, if necessary (e.g., a WEA or MAA is unavailable).

A simplified schematic of the MAA operations is provided in Figure 1-3.

*Fissile materials* loaded into *Assay Containers* in WEAs will be radiologically counted in a MAA to establish $^{235}U$ mass content. In addition, other solid wastes generated from HDP remediation areas and the site WTS may be directly transferred to a MAA for assay.

The MAA operations are summarized below:

1) A CD loaded with an *Assay Container* is received and accepted at a MAA;
2) The *Assay Container* is removed from the CD and placed into the counting position at the assay equipment (note that in some cases the entire CD may be the *Assay Container)*;
3) The assay equipment calibration routine is selected and the radiological counting initiated;
4) Following counting, the total $^{235}U$ content established for the *Assay Container* is recorded and the container dispositioned as follows:
   - In the event the total $^{235}U$ content of the *Assay Container* is estimated to be less than or equal to 15 $g^{235}U$, the *Assay Container* is declared a *Waste Container*, removed from the MAA, and dispositioned as *NCS Exempt Material.*
   - In the event the total $^{235}U$ content of the *Assay Container* is estimated to be greater than 15 $g^{235}U$, the *Assay Container* is declared a *Fissile Material Container,* marked with a unique identification number, and accompanied by paperwork describing the fissile contents (i.e., a description of the waste, its origin, and its total estimated $^{235}U$ gram content); and
5) The labeled *Fissile Material Container* and accompanying paperwork are placed into a sealed CD and removed from the MAA and transferred to a CDRA or FMSA for storage*.

### 1.4.6 Collared Drum Repack Area(s)

Depending on the generation rate of *Fissile Material Containers* during remediation work and their fissile loading, it may be desirable to consolidate the content of CDs. This could be particularly likely in the event of storage of a large number of CDs in a FMSA, with the majority of CDs containing only small quantities of *fissile material.* CDRAs may be used for these CD repack operations. For efficiency and to reduce CD handling, loaded CDs identified as potentially requiring repack may also be interim stored in a CDRA.

Any CDRAs used for HDP operations will be established within an enclosed structure to protect the CDs within their environs against accident disturbance and to afford access control and shelter from precipitation and the environment.

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* Note that future disposition of *Fissile Material Containers* in any FMSA is not addressed in this NCSA and will be covered under documented case-specific NCSAs.

### 1.4.7 Fissile Material Storage Area(s)

FMSAs are used to store CDs with known fissile content. Operations conducted in a FMSA concern only CD receipts, storage, and export. FMSAs employed for HDP operations will be established within an enclosed structure to protect the CDs within their environs against accident disturbance, and to afford access control and shelter from precipitation and the environment.

## 1.5 Overview of Equipment used for Waste Evaluation and Assay Activities

This section provides an overview of safety significant equipment employed for waste evaluation and assay activities, as relevant to this NCSA.

### 1.5.1 WEA Sorting Tray

The WEA sorting tray is used to evaluate the contents of each materials tipped on to its surface. The sorting tray is designed to ensure that solids and liquids tipped onto its surface will be contained in the tray, based on its impermeable construction and on its sizing and raised edge profile.

### 1.5.2 Field Containers

*Field Containers* are readily identifiable and are used to containerize loose *fissile materials* and suspect *fissile materials* identified during operations in HDP remediation areas. Each *Field Container* possess a maximum volumetric capacity of 20 liters (equivalent to the volume of a nominal 5 gallon container). This limited volume minimizes the potential to accommodate an unsafe mass of *fissile material.*

### 1.5.3 Assay Containers

*Assay Containers* are readily identifiable and are used to containerize loose *fissile materials* and suspect *fissile materials* identified during waste evaluation operations in a WEA.

### 1.5.4 Waste Containers

*Waste Containers* are used to containerize materials classified as *NCS Exempt Material* during waste evaluation operations in a WEA.

### 1.5.5 Fissile Material Containers

*Fissile Material Containers* are readily identifiable and are used to containerize *fissile materials* with assigned $^{235}$U mass estimates obtained at a MAA.

### 1.5.6 Collared Drums

Collared Drums (CDs) are used for *Field Container*, *Assay Container* or *Fissile Material Container* transit between functional areas of the site, and for *Field Container*, *Assay Container* or *Fissile Material Container* staging/storage. Each CD has a cylindrical geometry, possessing a minimum internal diameter of 57cm. This geometry and dimension ensures that an unlimited quantity of CDs, each loaded with up to 350 g $^{235}$U, will remain safely subcritical in any unstacked configuration (Ref. 20).

Each CD, irrespective of dimension, is fitted with a collar that extends 18" beyond the external radial surface of the CD. The CD collar is designed to ensure that any un-stacked arrangement of CDs would guarantee a minimum 36" separation distance between the outer surfaces of the CDs. The affixed collar is permanently secured to the CD and is not removed at any time the CD is being used, except when secured in a FMSA or CDRA.

#### 1.5.7 Fissile Material Monitoring Equipment

The *fissile material* monitoring equipment employed for the HDP comprise, but is not limited to, NaI scintillator probes, hand-held gamma survey instruments, and HRGS. Other assay equipment may be used provided the equipment satisfies the functional requirements credited in this NCSA.

The NaI scintillator probes and hand-held gamma survey instruments used are suitable for the detection of gamma radiation from uranium sources at the full range of enrichment. When calibrated and used in accordance with applicable procedures, this equipment provides confidence in the avoidance of unrevealed or underestimated potential $^{235}U$ content of any surveyed item.

The HRGS equipment is used to obtain nuclide specific abundance, and in particular, $^{235}U$ assay. The HRGS equipment automatically analyzes the assay data to produce an estimate of the $^{235}U$ content of the item presented for assay. When calibrated and used in accordance with applicable procedures, this equipment provides confidence in the avoidance of unrevealed or underestimated $^{235}U$ content of any surveyed item.

### 1.6 Scope of Assessment

The remediation activities assessed in this NCSA encompass waste evaluation and assay activities at the Hematite site. These operations are described in Sections 1.4.4 and 1.4.5. The scope of materials assessed in this NCSA is limited to the following:

- Materials exhumed from HDP remediation areas; and
- Solid waste recovered from the site WTS.

In the event that any materials not originating from a HDP remediation area or the site WTS require evaluation/assay in a WEA/MAA, approval shall first be obtained from the NCS Organization.

The following activities are specifically excluded from this assessment:

- HDP remediation area operations. These operations are evaluated in References 14 and 17.
- Activities related to D&D operations associated with removal of remaining equipment and structures in the former process buildings, and building decontamination and demolition. It is planned that these activities will be conducted under a separate safety case.
- Operations associated with staging and buffer storing loaded CDs (refer to Section 1.4.2 and 1.4.3 for a description of CD staging and buffer storage). These operations are evaluated in Reference 18, which also evaluates operations related to the transfer of materials across the site.
- CD repacking or batching operations in a designated CDRA (refer to Section 1.4.6 for a

description of a CDRA). The criticality safety assessment of these operations is provided in Ref. 16.

- Storage of containerized *fissile material* (i.e., material containing $^{235}U$ in a quantity/concentration sufficient to require NCS controls/oversight) in a designated FMSA (refer to Section 1.4.7 for a description of a FMSA). The criticality safety assessment of *fissile material* storage in designated FMSAs is provided in Ref. 13.
- Activities related to the management and collection of site water, including water collected from the burial pits during their remediation. The criticality safety assessment of water collection, treatment, and management activities is addressed in Ref. 12.
- Inspection, swabbing, and monitoring of additional waste items that will be produced during, and as a result of, the HDP site remediation activities (e.g., buried waste exhumation and contaminated soil remediation operations). These process wastes may comprise items such as protective clothing, hoses, swabs, and tools. Typically, these items can be seen to be free of significant quantities of *fissile material* by inspection and swabbing. The nature of the items is such that, by virtue of their composition, shape or form, they cannot act as efficient reflectors or moderators.
- The transportation of recovered *fissile material* and *fissile material* samples off the Hematite site (e.g., to an offsite waste facility or an offsite sampling laboratory). The transportation of *Fissile Material Containers* from the Hematite site will be performed under either a generic or case-specific evaluation.

## 1.7 Methodology

### 1.7.1 NCSA Approach

This NCSA uses a risk-informed approach. Risk insights, gained from the findings of the risk assessment, are used to establish aspects of the design and process susceptible to faults important to nuclear criticality safety.

The risk informed approach is complemented with an As Low As Reasonably Achievable (ALARA) assessment that is focused on identifying practicable measures that can be reasonably implemented to further reduce the risk of criticality to a level as low as is reasonably achievable. The ALARA assessment also serves to provide an additional degree of confidence that a criticality incident resulting from the activities assessed is not credible.

In summary, the approach used in this NCSA is as follows:

1) Establish the margin of safety between normal (i.e., expected) conditions and foreseen credible abnormal conditions.
2) Determine whether the inherent margin of safety is sufficient to safely accommodate the credible deviations from normal conditions, and if not, identify feature(s) of the process* that

* In the selection of safety controls, preference is placed on use of engineered controls over procedural controls.

are important to ensuring criticality safety under all credible conditions.

3) Establish what additional practicable measures, if any, can reasonably be implemented to ensure that the risks from criticality are as low as is reasonably achievable.

### 1.7.2 Criticality Control Philosophy

This section provides an overview of the criticality control philosophy for the scope of operations addressed in this NCSA (Section 1.6). The specific safety measures established in support of these operations are derived in the assessment of abnormal condition event sequences in Section 2.4.

#### 1.7.2.1 Fissile Material Extraction, Containerization, and Handling Prior to Assay

The general philosophy for handling of CDs with un-evaluated/un-assayed content is to ensure that the conditions experienced by the containerized materials do not become more onerous than those previously experienced. This, in large measure, is achieved by the soil/waste extraction and containerization practices documented in References 12, 14, and 17.

For prudence and caution, all CDs loaded with materials exhumed from a HDP remediation area or recovered from the WTS are treated as high fissile content containers until proven otherwise by radiological screening at a WEA, or radiological counting at a MAA. Because of their high fissile content assumption, it is important that the content of only one CD is processed within any individual WEA or within any individual MAA at any one time.

The available evidence on wastes (Ref. 9) indicates that fissile liquids are not present. However, it is prudent to treat all containerized liquids with caution as potentially containing *fissile material*. Any containerized liquids discovered during waste evaluation operations (e.g., bottles containing liquids) will not be evaluated beyond the point of discovery without specialist advice from the NCS Organization.

#### 1.7.2.2 Container Handling Following Assay

All *fissile materials* loaded into *Assay Containers* in WEAs will be radiologically counted at a MAA to establish $^{235}$U mass content. Following counting, the total $^{235}$U content established for the *Assay Container* is used to determine the disposition of the container, as follows:

- In the event the total $^{235}$U content of the *Assay Container* is estimated to be less than or equal to 15 g$^{235}$U, the *Assay Container* is declared a *Waste Container*, removed from the MAA, and dispositioned as *NCS Exempt Material.*
- In the event the total $^{235}$U content of the *Assay Container* is estimated to be greater than 15 g$^{235}$U, the *Assay Container* is declared a *Fissile Material Container,* marked with a unique identification number, and accompanied by paperwork describing the fissile contents (i.e., a description of the waste and its total estimated $^{235}$U gram content). The labeled *Fissile Material Container* and accompanying paperwork is subsequently removed

from the MAA and transferred to a FMSA for interim storage*.

All *Fissile Material Containers* are recorded in a central system - the site Criticality Control Inventory System (CCIS), immediately following radiological assay at a MAA. The CCIS provides a means to record all *Fissile Material Containers* as they are generated across the site. The CCIS runs in parallel to the Material Control and Accountability (MC&A) system and the Material Custodian will be responsible for both. However, the MC&A system **does not** form part of the CCIS and is not necessarily aligned. The CCIS is not intended to provide a means to control fissile mass for NCS purposes because the criticality safety basis for each functional area of the site that is approved to contain *fissile material* is based on either single container limits (i.e., processing only one container at a time) or on the provision of interaction controls that assure safe separation of containers in staging or storage areas. Instead, the CCIS is intended to provide a basis for monitoring the global inventory of *fissile material* across the site, which has the benefit of providing a documented basis to track and monitor *fissile material* accumulation rates.

Following the transfer and receipt of any *fissile material* package at an off-site facility (e.g., an off-site sampling laboratory or waste acceptance facility), the site *CCIS* log is updated and the *fissile material* balance adjusted accordingly (i.e., reduced).

* Note that future disposition of *Fissile Material Containers* in any FMSA is not addressed in this NCSA and will be covered under documented case-specific NCSAs.

# 2.0 CRITICALITY SAFETY ASSESSMENT

The criticality safety assessment is organized as follows:

- **Section 2.1** describes the hazard identification technique employed in the criticality safety assessment of waste evaluation and assay activities and provides a summary of the hazard identification results.
- **Section 2.2** outlines the generic assumptions used in the criticality safety assessment.
- **Section 2.3** contains the criticality safety assessment of waste evaluation and assay activities under normal (i.e., expected) conditions.
- **Section 2.4** contains the criticality safety assessment of waste evaluation and assay activities under abnormal (i.e., unexpected) conditions.

## 2.1 Criticality Hazard Identification

This section outlines the technique used to identify criticality hazards associated with the waste evaluation and assay activities outlined in Section 1.3. A summary of the hazards identified is also provided, together with a brief description of their disposition in the NCSA.

### 2.1.1 Hazard Identification Method

The hazard identification technique employed for the criticality safety assessment of waste evaluation and assay activities is based on the *What-If/Checklist* analysis method. The *What-If/Checklist* analysis technique is a combination of two hazard evaluation methods: *What-If* analysis and *Checklist* analysis. This evaluation technique is a brainstorming approach in which a group or team familiar with the facility equipment and processes ask questions or voice concerns about possible undesirable events. The checklist adds a systematic nature to the process by ensuring all applicable hazards are addressed. The *What-If/Checklist* method identifies hazards, hazardous situations and specific events that could produce undesirable consequences. Consequences and existing controls are listed and suggestions are made for further risk reduction.

As part of the *What-If/Checklist* analysis, the eleven (11) criticality safety controlled parameters are examined to determine the extent of their importance to criticality safety for each activity identified in the remediation objectives (Section 1.3).

The eleven (11) criticality safety controlled parameters examined include:

- Geometry
- Interaction
- Mass
- Isotopic/Enrichment
- Moderation
- Density
- Heterogeneity
- Neutron Absorbers

- Reflection
- Concentration
- Volume

The eleven (11) parameters listed above are traditionally considered in criticality safety assessments of processes at operating facilities possessing SNM. Typically, the non-processed based nature of decommissioning operations limits the ability to control many parameters, resulting in the need to use bounding values for parameters in the NCSA in many instances.

### 2.1.2 Hazard Identification Results

A summary of the criticality hazards identified from the *What-If/Checklist* analysis is presented in Table 2-1 and are based on Reference 15. Hazards that result in events with similar consequences and safeguards are grouped in single criticality accident event sequences (analyzed in Section 2.4).

Table 2-1 Criticality Hazards Identified from the Waste Evaluation and Assay Activities What-if/Checklist Analysis

| Event ID | What-if | Causes | Consequences | Accident Sequence in NCSA |
|---|---|---|---|---|
| **Geometry** | | | | |
| There are no identified hazards associated with geometry because the safety assessment of waste evaluation and assay activities is based on subcritical limits derived for idealized spherical geometry uranium-water mixtures that are optimally-moderated and full water reflected. | | | | |
| **Interaction** | | | | |
| There are no identified hazards associated with interaction because the safety assessment of waste evaluation and assay activities assumes that all material outside the environs of a CD is assembled in one location. Note that interaction between CDs staged in a WEA or MAA is generically assessed in Reference 18. | | | | |
| **Mass & Concentration** | | | | |
| WEA-C-01 | A collared drum containing a large mass of uranium is received at a WEA. | • Undocumented consignment of process waste, with high fissile content, to a burial pit. | Potential for a CD received in a WEA to contain more than a maximum safe mass of $^{235}U$. | **Section 2.4.1** |
| WEA-C-02 | There is an accumulation of *fissile material* within a WEA. | • Processing of multiple CDs in a WEA at any one time.<br>• Long term accumulation of *fissile material* within a WEA from waste evaluation activities. | Potential to assemble more than a maximum safe mass of $^{235}U$ in a WEA (excluding the contents of materials sealed in any staged CDs). | **Section 2.4.2** |
| WEA-C-03 | Fissile material is transferred from a WEA to a WHA. | • Failure to identify *fissile material* during waste evaluation operations.<br>• Erroneous placement of *fissile material* (identified during waste evaluation operations) into a *Waste Container*.<br>• Mislabeling of *Assay Containers* as waste.<br>• Misdirection of *Assay Containers* to a WHA. | Potential to assemble more than a maximum safe mass of $^{235}U$ in a WHA. | **Section 2.4.3** |

| Event ID | What-if | Causes | Consequences | Accident Sequence in NCSA |
|---|---|---|---|---|
| WEA-C-04 (see note 1) | Excess *fissile material* is transferred from a WEA to a MAA. | • Failure to identify *fissile material* during waste evaluation operations.<br>• Overloading *Assay Containers* during waste evaluation operations. | Potential to assemble more than a maximum safe mass of $^{235}U$ in a *Assay Container.* | **Section 2.4.4** |
| MAA-C-01 | There is an accumulation of *fissile material* within a Material Assay Area. | • Unloading of multiple CDs within a MAA at one time. | Potential to assemble more than a maximum safe mass of $^{235}U$ in a MAA (excluding the contents of materials sealed in any staged CDs). | **Section 2.4.5** |
| MAA-C-02 | Low fissile mass is assigned to an *Assay Container* following assay. | • Equipment failure.<br>• Incorrect labeling of a container such that the assigned mass is less than the actual mass established by HRGS assay. | Improper disposition of *fissile material* as *NCS Exempt Material*,<br>or<br>Improper transit of a CD with a high $^{235}U$ loading to a CDRA or FMSA, resulting in less spacing being applied in a CDRA/FMSA than would be appropriate for the actual fissile mass content of the CD. | **Section 2.4.6** |
| MAA-C-03 | High fissile mass content is assigned to an *Assay Container* following assay. | • Large quantity of $^{235}U$ residues within an *Assay Container.* | Potential for a single CD in a MAA to contain more than a maximum safe mass of $^{235}U$, and, for an unanalyzed condition to be realized in the event of transfer of the subject CD to other functional areas of the site. | **Section 2.4.7** |

<table>
<tr><th>Event ID</th><th>What-if</th><th>Causes</th><th>Consequences</th><th>Accident Sequence in NCSA</th></tr>
<tr><td colspan="5">Isotopic/Enrichment</td></tr>
<tr><td colspan="5">There are no identified hazards associated with presence of variable enrichment uranium in solid wastes generated from the waste evaluation and assay activities. This is because the safety assessment is conservatively based on subcritical limits derived for uranium with 100 wt.% $^{235}$U/U enrichment.</td></tr>
<tr><td colspan="5">Moderation</td></tr>
<tr><td colspan="5">There are no identified hazards associated with moderation because the safety assessment of waste evaluation and assay activities is based on subcritical limits derived for idealized spherical geometry uranium-water mixtures that are optimally-moderated and full water reflected.</td></tr>
<tr><td colspan="5">Density</td></tr>
<tr><td colspan="5">There are no identified hazards associated with presence of variable density uranium because the safety assessment of waste evaluation and assay activities is conservatively based on subcritical limits derived for uranium metal at maximum theoretical density.</td></tr>
<tr><td colspan="5">Heterogeneity</td></tr>
<tr><td colspan="5">There are no identified hazards associated with the presence of heterogeneous distributions of uranium (i.e., solid pieces of SNM or an conglomeration of SNM particulate) because the safety assessment of waste evaluation and assay activities:<br>• Is conservatively based on subcritical limits derived for homogeneous uranium-$H_2O$ mixtures (with 100 wt.% $^{235}$U/U enrichment), for which subcritical limits are smaller than equivalent heterogeneous uranium-$H_2O$ mixtures; and<br>• The potential impact of $^{235}$U mass underestimation during radiological survey/assay in a WEA/MAA due to the potential variation in uranium distribution and particle size is addressed in Sections 2.4.3 and 2.4.6.</td></tr>
<tr><td colspan="5">Neutron Absorbers</td></tr>
<tr><td colspan="5">There are no identified hazards associated with absence of fixed neutron absorbers because the safety assessment of waste evaluation and assay activities does not credit fixed neutron absorbers.</td></tr>
<tr><td colspan="5">Reflection</td></tr>
<tr><td colspan="5">There are no identified hazards associated with reflection conditions because the safety assessment of waste evaluation and assay activities is based on subcritical limits derived for idealized spherical geometry uranium-water mixtures that are optimally-moderated and full water reflected.</td></tr>
<tr><td colspan="5">Volume</td></tr>
<tr><td colspan="5">Volume control is credited in the evaluation of loose materials in a WEA, however no credible criticality accident event sequences related to loss of volume control have been identified.</td></tr>
</table>

Source: Events are identified in Ref. 15.

NOTES: 1. This event sequence was identified subsequent to the identification of events in Ref. 15 and is based on engineering judgment.

## 2.2 Generic Safety Case Assumptions

This section outlines the generic assumptions on which this criticality safety assessment is based.

### 2.2.1 Fissile Material Assumptions

The pertinent underlying assumptions of this NCSA related to the assessed waste evaluation and assay activities are as follows:

- This assessment does not consider fissile nuclides other than $^{235}U$. Based on the history of the site and site documentation (refer to Section 1), there is no expectation that fissile nuclides other than $^{235}U$ could exist within the site boundary.
- The materials evaluated/assayed in WEAs/MAAs include only materials exhumed from HDP remediation areas and solids recovered from the site WTS. In the event that any materials not originating from a HDP remediation area or the site WTS require evaluation/assay in a WEA/MAA, approval shall first be obtained from the NCS Organization.
- Fissile material limits have been derived assuming homogeneous mixtures of $^{235}U$ and water ($H_2O$). This approach is conservative with respect to other materials containing uranium, including process wastes.
- The *fissile material* associated with buried wastes and contaminated soils is predominantly insoluble particulates of uranium as opposed to dissolved, or water-soluble compounds. The available evidence on wastes (Ref. 14) indicates that fissile liquids are not present. However, it is prudent to treat all containerized liquids with caution as potentially containing *fissile material*. For this reason, any containerized liquids discovered during waste evaluation operations (e.g., bottles containing liquids) will not be evaluated beyond the point of discovery without specialist advice from the NCS Organization.

### 2.2.2 Operational Practice and Equipment Assumptions

The pertinent underlying assumptions of this NCSA related to the operational practice and equipment used for the waste evaluation and assay activities addressed are as follows:

- The waste evaluation and assay activities are as described in Section 1.4.
- The safety related equipment used for the waste evaluation and assay activities outlined in Section 1.4 are as described in Section 1.5.

## 2.3 Normal Conditions

This section contains the criticality safety assessment of waste evaluation and assay activities under normal (i.e., expected) conditions.

Based on historical knowledge of site activities and site characterization data, it is expected that CDs containing *fissile materials* and other items extracted from HDP remediation areas for evaluation/assay in a WEA/MAA will likely comprise material with some degree of $^{235}U$ contamination. However, the quantities of $^{235}U$ involved are expected to be very small under normal conditions with up to a few grams $^{235}U$ per CD on an average basis and up to a few tens of grams $^{235}U$ per CD on an intermittent basis (refer to References 14 and 17 for justification). The expected low fissile loading of CDs received at WEAs/MAAs for evaluation/assay is also sustained for CDs containing solid wastes recovered from the site WTS. This expectation is supported by the NCSA of water collection and treatment activities (Ref. 12) which determines that solid wastes from the WTS would be expected to contain trivial $^{235}U$ loading.

The expected low $^{235}U$ loading of each CD received at a WEA/MAA for evaluation/assay, and the normal practice of only evaluating/assaying the content of one CD at any one time, support the conclusion that there is no conceivable scenario in which a maximum safe $^{235}U$ mass of 760 g$^{235}U$ could be assembled within a single location of a WEA or MAA under normal conditions. Based on the anticipated $^{235}U$ loadings, very large margins of safety are expected under normal conditions.

Note that under normal conditions a small congregation of unopened CDs may reside in a WEA/MAA while awaiting evaluation/assay of their content. The safety of congregation of loaded CDs is generically assessed in Reference 18. Based on the assessment in Reference 18 and the maximum few tens of grams $^{235}U$ loading per CD under normal conditions, any congregation of CDs within a WEA/MAA under normal conditions will be safely subcritical.

## 2.4 Abnormal Conditions

This section provides an assessment of the criticality hazards identified from the *What-if* analysis conducted for the waste evaluation and assay activities addressed in this NCSA (Section 1.6). The *What-if* analysis (summarized in Table 2-1) identified potential criticality hazards requiring further evaluation. The postulated hazards are grouped and assessed in the following event sequences:

- Section 2.4.1: A Collared Drum Containing a Large Mass of Uranium is Received at a WEA.
- Section 2.4.2: There is an Accumulation of Fissile Material within a WEA.
- Section 2.4.3: Fissile Material is Transferred from a WEA to a WHA.
- Section 2.4.4: Excess Fissile Material is Transferred from a WEA to a MAA.
- Section 2.4.5: There is an Accumulation of Fissile Material within a MAA.
- Section 2.4.6: Low Fissile Mass is Assigned to an *Assay Container* following Assay
- Section 2.4.7: High Fissile Mass Content is Assigned to an *Assay Container* following Assay.

### 2.4.1 A Collared Drum Containing a Large Mass of Uranium is Received at a WEA

#### 2.4.1.1 Discussion

The NCSA of buried waste and contaminated soil remediation activities (Ref. 17) establishes Criticality Safety Controls (CSCs) to ensure that the following items are identified, individually extracted and containerized in CDs during visual inspection of HDP remediation areas:

1) Any items with the potential to contain *fissile material* (e.g. a process filter);
2) Items that resemble intact containers;
3) Bulky objects with linear dimensions exceeding the permitted *cut depth*; and
4) Metallic items.

The abovementioned items are treated equivalently to item(s) or region(s) known to contain *fissile material* (from the results of the in-situ radiological surveys) because of their potential to contain *fissile material*, and because of the possibility that the in-situ radiological surveys could have be in-effective in detecting any fissile content.

In the event that an item resembling an intact container or other bulky object did contain a large mass of uranium, it is possible that its evaluation in a WEA could result in an unsafe condition.

#### 2.4.1.2 Risk Assessment

An intact container or other bulky object containerized in a CD would have to contain greater than a maximum subcritical mass of 760 $^{235}$U to present a criticality hazard. This potential is examined in Section 2.4.8.2 of Reference 17, where it is concluded that such an event would be very improbable. The same assessment also concludes that even if an intact container or other bulky object containing >760 $^{235}$U were recovered from a HDP remediation area, the contents of the exhumed item would have to attain a more reactive configuration, during and/or subsequent to retrieval than currently experienced to result in a criticality. Recognizing the high likelihood that any recovered item would not contain uranium in the idealized geometry, concentration, moderation, and reflection conditions upon which the maximum subcritical mass limit of 760 $^{235}$U is based, it is almost certain that significant (i.e., kilogram) quantities of $^{235}$U would have to be recovered in a single item before a criticality incident could be credible. If this were possible it is more probable that a criticality incident would have occurred in-situ rather than during or immediately subsequent to removal of the item. Specifically, reflection conditions would be expected to be substantially reduced during and following retrieval than compared to the in-situ condition. Furthermore, based on the CSCs established in Section 2.4.7.4 of Reference 17, neutron interaction conditions would be expected to be negligible following removal, but could potentially be significant while in-situ. These two points, coupled with the improbability of encountering very large quantities of uranium in a single item, ensure subcriticality during recovery and handling of an intact container or other bulky object.

Although there is no potential for a criticality accident during recovery or handling of an intact container or other bulky object, evaluation of the container/object in a WEA could potentially configure its content into a more reactive condition. For example, although extremely remote, it is possible that an item with a very high fissile mass content could be subcritical in-situ and following retrieval and handling due to the geometry of its packaging, such as a small diameter bottle. However, subsequent reconfiguration of the *fissile material* on the surface of a sorting tray in a WEA could potentially result in the material achieving a more reactive condition. In practice, waste evaluation operations would tend to render any *fissile material* in a less reactive condition due to the spreading of the material into a thin layer configuration. This would generally result in inefficient geometry and reflection conditions. However, under extreme scenarios involving exceptionally high fissile content and inadvertent manipulation to create an efficient geometry and reflection conditions, it is possible that an unsafe condition could arise. For this reason, it is necessary to establish CSCs to preclude the potential to manipulate materials with high fissile content. This is reflected by the following requirements:

- The volume of loose material evaluated at any one time on a WEA sorting tray shall be limited to a maximum of 20 liters (equivalent to the volume of a nominal 5 gallon container)*; and
- In the event of discovery of bottles containing liquids or significant quantities of uranium products such as pieces of metal, pellets/pellet fragments or powders, operations in the affected area shall be curtailed and shall not resume without specialist advice from the NCS Organization.

The requirement to limit the volume of loose material evaluated at one time to a maximum of 20 liters, combined with the *Fissile Material Exhumation Limit*† of 38 g $^{235}$U/10L, limits the content of evaluated material to a maximum of 76 g $^{235}$U at one time. This maximum mass is an order of magnitude smaller than the 760 g $^{235}$U (Table A-1) maximum safe mass established for an idealized, optimally-moderated, full water reflected, spherical-geometry system. Thus, the requirements noted above afford a very large margin of safety. While these arguments do not strictly apply to bulky objects such as a single piece of equipment (because their volume may exceed 20 liters), the risk presented by such items would be expected to be small in comparison to items known to contain *fissile material*. It is not credible that the degree of safety margin for evaluation of these items would be significantly reduced. For example, the ten highest inventory waste consignments to site burial grounds, combined, do not contain sufficient fissile mass to present a criticality hazard, even if their recorded $^{235}$U mass content estimates were underestimated by 100% (refer to Section 2.4.3.2 of Reference 17 for details). In practice, larger safety margin (i.e., more than a factor of ten) would exist for evaluation of bulky objects.

* This requirement only applies to loose materials (e.g., the material content of exhumed intact containers) and does not apply to bulky objects such as a piece of equipment.

† The *Fissile Material Exhumation Limit* of 38 g $^{235}$U/10L represents the highest permitted concentration of *fissile material* that may be transferred to a WEA under non-exceptional circumstances.

WEA operations inherently requires administrative functions. The inevitable variability in the types of materials that may be received for evaluation necessitates the need to rely on human agency to fulfill the requirements noted above. Training is essential for any nuclear facility decommissioning activity and operations in a WEA are treated no differently. The WEA operators are knowledgeable, trained, and qualified to perform their assigned tasks, and fully recognize the importance in performing their tasks independently and according to procedure. This, combined with the following, ensures that the abovementioned controls would be at least unlikely to fail:

- Provision of simple and unambiguous procedures;
- The very low probability of encountering significant uranium concentrations; and
- The very large factor of safety (ten) between the *Fissile Material Exhumation Limit* ($38g^{235}U/10L$ ) and the safety limit ($380g^{235}U/10L$) for waste evaluation operations.

To ensure that the preventative measures established above provide sufficient risk reduction it is necessary to require that each individual procedure is independently performed by multiple (i.e., at least two) persons. The control reliability arguments presented above, combined with the use of multiple persons, ensures that this event sequence satisfies the Double Contingency Principle (DCP), because two unlikely concurrent failures would be required before a criticality accident could be possible.

#### 2.4.1.3 Summary of Risk Assessment

Based on the risk assessment provided in Section 2.4.1.2, evaluation of an exhumed intact container or other bulky object in a WEA could potentially render its content in a more reactive condition. However, the following conditions must exist before a criticality accident would be possible:

- Independent CSCs would have to be compromised to the extent that there is chronic noncompliance with the following requirements:
  - the volume of material evaluated at any one time on a WEA sorting tray shall be limited to a maximum of 20 liters (equivalent to the volume of a nominal 5 gallon container); and
  - any suspect items (e.g., bottles containing liquids or significant quantities of uranium products such as pieces of metal, pellets/pellet fragments or powders) shall not evaluated beyond the point of discovery without specialist advice from the NCS Organization; and
- The evaluated object/material would have to contain greater than a maximum safe mass of 760 $g^{235}U$, which is essentially equivalent to the total $^{235}U$ mass loading associated with an entire burial pit.

The following additional criteria serve to further decrease the likelihood of a criticality accident:

- The exhumed uranium would have to be of a high $^{235}U$ enrichment; and

- Non fissile and non hydrogenous elements (e.g., soil) would have to be absent, or at least present in small quantities within the waste matrix/assembled $^{235}U$ accumulation (otherwise these constituents would result in dilution and parasitic neutron absorption).

#### 2.4.1.4 Safety Controls

The explicit CSCs related to evaluation of an exhumed intact container or other bulky object in a WEA are established below. These CSCs are credited to provide the criticality safety barriers identified above. No additional practicable measures for further reducing criticality risk have been identified. It is judged that the risks from criticality are as low as is reasonably achievable.

**Administrative CSC 01:** *The volume of loose material evaluated at any one time on a WEA sorting tray SHALL be limited to a maximum of 20 liters (equivalent to the volume of a nominal 5 gallon container).*

<u>Notes:</u>

1. *This CSC only applies to loose materials (e.g., the material content of exhumed intact containers) and does not apply to bulky objects such as a piece of equipment.*

**Administrative CSC 02:** *In the event of discovery of bottles containing liquids or significant quantities of uranium products such as pieces of metal, pellets/pellet fragments or powders, operations in the affected area SHALL be curtailed and SHALL NOT resume without specialist advice from the NCS Organization.*

**Administrative CSC 03:** *All waste evaluation operations SHALL be independently observed for adherence to procedure by at least one individual.*

The CSCs relevant to ensuring that any loose material would have a fissile concentration not exceeding the *Fissile Material Exhumation Limit* of 38 g$^{235}$U/10L are provided in References 14 and 17 and are not repeated here for brevity. However, these CSCs are listed in Section 3 for completeness.

### 2.4.2 There is an Accumulation of Fissile Material within a WEA

#### 2.4.2.1 Discussion

All *fissile materials*, suspect *fissile materials*, items resembling intact containers, bulky objects, and metallic items identified during operations in a HDP remediation area will be containerized (individually) in CDs and ultimately transferred to a WEA for evaluation of fissile content. In addition, solids recovered from the WTS will be containerized in CDs and may be transferred to a WEA for evaluation of fissile content.

Following WEA operations, *fissile materials* are transferred to a MAA for radiological counting to establish $^{235}U$ mass content*. The general aim of waste evaluation operations is to identify and extract uranium associated with the material content of an incoming CD that would be of concern from a NCS perspective. Identification of uranium is achieved by spreading/disassembling the material content of the CD across the surface of a sorting tray, and using hand-held gamma survey instruments and visual inspection to locate the uranium.

In the event that multiple CDs are processed in a WEA at one time, or *fissile material* is not completely removed from a WEA prior to accepting and processing a new CD, it is possible that an accumulation of *fissile material* could occur. Chronic accumulation of *fissile material* in a WEA could result in collection of a fissile mass in excess of the maximum subcritical mass limit of 760 g $^{235}U$, presenting a criticality risk.

Note that the potential for a criticality accident due to congregation of unopened CDs in a WEA is generically assessed in Reference 18 and is not re-addressed in this event sequence. Based on the assessment in Reference 18, there is no restriction on allowing multiple CDs to reside in a WEA because the geometry and design of CDs ensures their safety when arranged in any unstacked configuration. Also note that the CSCs established in Section 2.4.1.4 and 2.4.2.4 to safeguard processing of multiple CDs in a WEA at any one time also precludes the potential for unsafe interaction between CDs staged in a WEA and material being evaluated on a WEA sorting tray.

#### 2.4.2.2 Risk Assessment

Two potential mechanisms exist to accumulate *fissile material* in a WEA and are associated with:

- Processing the content of multiple CDs in a single WEA at any one time; and
- Long term accumulation of *fissile material* within a WEA from waste evaluation activities.

Both of the *fissile material* accumulation mechanisms noted above are assessed below.

* Note that in some instances, the content of a CD may not actually be 'evaluated' in a WEA (e.g., due to the potential for hazardous material content). These CDs may be transferred directly to a MAA for assay. Also note that CDs may be buffer stored in a CDBS at any time, if necessary (e.g., a WEA or MAA is unavailable).

Processing Multiple CDs in a WEA at one time

The content of CDs received at a WEA for evaluation represent materials with un-assigned/unknown fissile content. For this reason, it is prudent that all loaded CDs received at a WEA are treated as high fissile content containers until proven otherwise by waste evaluation operations. Because of this high fissile content assumption, it is important that the content of only one CD is processed within any individual WEA at any one time. Consequently, it is necessary to establish CSCs to ensure that the content of only one CD is processed within any individual WEA at any one time.

Long Term Accumulation of Fissile Material in a WEA

The potential for a criticality incident due to gradual, long term, accumulation of *fissile material* in a WEA is very remote because:

- The quantity of $^{235}U$ associated with any received CD is expected to be very low (refer to Section 2.3); and
- The potential to collect and retain *fissile material* in a WEA is very limited due to the simple design and limited operations within the area (refer to Section 1.4 for details).

Based on the assessment provided in Section 2.4.10.2 of Reference 17, it is clear that CDs loaded with materials exhumed from HDP remediation areas with known burials (i.e., burial pits) have the greatest potential for significant $^{235}U$ loading. The site burial logs indicate that the vast majority of the 15,000 waste consignments to burial pits were assigned a nominal 1 g $^{235}U$ inventory, based on the limit of detection capability (Ref. 6). Only a very small number of waste consignments (ten) involved non-trivial $^{235}U$ loadings. Even the ten highest inventory waste consignments, combined, do not contain sufficient fissile mass to present a criticality hazard, even if their recorded $^{235}U$ mass content estimates were underestimated by 100% (refer to Section 2.4.3.2 of Reference 17 for details). Thus, accumulation of a maximum subcritical mass of 760 g $^{235}U$ would, in practice, require receipt and evaluation of the content of a very large number of CDs.

The WEA operations encompass only CD receipt, content evaluation, and *Waste Container* and *Assay Container* loading. The CD content handling, evaluation, and container loading activities is confined to the WEA sorting tray and immediate surrounding area. While some degree of accumulation might be expected in this area (e.g., due to contamination of the sorting tray), it is expected that the associated fissile mass would be very small (i.e., up to a few grams). However, it is possible that gradual accumulation of *fissile material* in a WEA over time could occur. This potential is examined below for both *revealed* and *unrevealed* buildups of material.

*Revealed* buildup of *fissile material*

A *revealed* buildup of *fissile material* would be characterized by a readily identifiable accumulation of solid material, e.g., residual particulate on the WEA sorting tray, or pieces of solid waste spilled from the sorting tray onto the floor of the WEA. The potential for this type of accumulation mechanism to result in collection of an unsafe mass of *fissile material* would require chronic procedural violation. Specifically, the CSC established to safeguard processing of multiple CDs in a WEA at any one time, also precludes the potential for a long term *revealed* accumulation of *fissile material* in a WEA, to the extent required for criticality. Refer to Section 2.4.1 for further details.

*Unrevealed* buildup of *fissile material*

An *unrevealed* buildup of *fissile material* would be characterized by a spillage of solid *fissile material* into an area not readily accessible or inspectable, or by a spillage of fissile liquor onto an absorbent surface in the vicinity.

The potential for an *unrevealed* buildup of *fissile material* due to spillage of solids is mitigated by use of a sorting tray for waste evaluation operations, which provides a delineated surface for material evaluation. However, it is important that the sorting tray used for waste evaluation is physically bounded in order to prevent spillage of material from the surface of the tray into any potential inaccessible or un-inspectable areas. For this reason, the raised sides of the sorting tray are recognized as an important design feature that minimize the potential for spillage and accumulation of *fissile material* in a WEA.

It is inevitable that some CDs will contain wastes with some degree of water content due to the potential for water saturation of the environment from which the contained materials were exhumed. Additionally, the requirement to treat items resembling intact containers as items with potential fissile content (refer to Reference 17 for details) further increases the probability that some CDs will contain items with some liquid content. It is therefore reasonable to assume that tipping of the content of a CD onto the surface of a WEA sorting tray may result in a release of liquid to the surface of the tray. However, the design feature noted in the previous paragraph (i.e., the sorting tray equipped with raised sides) will ensure that any liquid spilled onto the surface of the sorting tray will be contained. In addition, the CSCs established in Section 2.4.1.4 further reduce the potential for an *unrevealed* buildup of *fissile material* due to spillage of liquids in a WEA.

The design feature noted above minimizes the potential to spill solids or liquids onto any surface other than the designated sorting tray. This is important to preventing an *unrevealed* buildup of *fissile material* in a WEA. Equally important are the following requirements:

- Prior to unloading the content of any CD in a WEA, the surface of the WEA sorting tray as well as the surrounding area shall be confirmed to be clear of any materials not contained in a *Waste Container* or CD or associated with fixed contamination of the WEA sorting tray surface.; and
- All waste evaluation operations shall be performed using only the designated sorting tray; and
- Spillage of the content of any container received in a WEA onto any surface other than the designated sorting tray shall be recovered as soon as is practicable and prior to evaluation of the content of any additional containers. In the event that the spillage

involved release of free liquids the NCS Organization shall be notified.

The inevitable variability in the types of materials that may be received for evaluation necessitates the need to rely on human agency to fulfill the above requirements. Training is essential for any nuclear facility decommissioning activity and operations in a WEA are treated no differently. The WEA operators are knowledgeable, trained, and qualified to perform their assigned tasks, and fully recognize the importance in performing their tasks independently and according to procedure. This, combined with the following, ensures that the abovementioned controls would be at least unlikely to fail:

- Provision of simple and unambiguous procedures; and
- The very low probability of encountering significant uranium concentrations.

To ensure that the preventative measures established above provide sufficient risk reduction it is necessary to require that each individual procedure is independently performed by multiple (i.e., at least two) persons. The control reliability arguments presented above, combined with the use of multiple persons, ensures that this event sequence satisfies the DCP, because two unlikely concurrent failures would be required before a criticality accident could be possible.

#### 2.4.2.3 Summary of Risk Assessment

Based on the discussion provided in Section 2.4.2.2, it is concluded that a criticality accident as a result of accumulation of *fissile material* within a WEA is not credible because:

- Independent CSCs would have to be compromised to facilitate:
  - the presence/processing of the content of more than one CD at any one time; or
  - spillage of the content of received CDs resulting in long term accumulation of *fissile material*; and

The following additional criteria serve to further decrease the likelihood of a criticality accident:

- The combined $^{235}U$ mass associated with the accumulated *fissile material* would have to exceed 760 g $^{235}U$; and
- The uranium associated with the accumulated *fissile material* would have to be of a high $^{235}U$ enrichment; and
- The uranium associated with the accumulated *fissile material* would have to be suspended at optimum, or near optimum, concentration in an efficient (i.e., water) moderating medium; and
- The uranium associated with the accumulated *fissile material* would have to be configured into a geometry that would favor a low critical mass system (i.e., assembled into a spherical or near spherical geometry); and
- Non fissile and non hydrogenous elements (e.g., soil) would have to be absent, or at least present in small quantities within the accumulated *fissile material*

(otherwise these constituents would result in dilution and parasitic neutron absorption).

#### 2.4.2.4 Safety Controls

The explicit CSCs related to preventing an accumulation of *fissile material* within a WEA are established below. These CSCs are credited to provide the criticality safety barriers identified above. No additional practicable measures for further reducing criticality risk have been identified in the risk assessment. It is judged that the risks from criticality are as low as is reasonably achievable.

**Administrative CSC 01:** *The volume of loose material evaluated at any one time on a WEA sorting tray SHALL be limited to a maximum of 20 liters (equivalent to the volume of a nominal 5 gallon container).*

*Notes:*

1. *This CSC only applies to loose materials (e.g., the material content of exhumed intact containers) and does not apply to bulky objects such as a piece of equipment.*

**Administrative CSC 02:** *In the event of discovery of bottles containing liquids or significant quantities of uranium products such as pieces of metal, pellets/pellet fragments or powders, operations in the affected area SHALL be curtailed and SHALL NOT resume without specialist advice from the NCS Organization.*

**Administrative CSC 03:** *All waste evaluation operations SHALL be independently observed for adherence to procedure by at least one individual.*

**Administrative CSC 04** *Prior to unloading the content of any CD in a WEA, the surface of the WEA sorting tray as well as the surrounding area SHALL be confirmed to be clear of any materials not contained in a Waste Container or CD.*

*Notes:*

1. *This CSC does not apply to any residual material associated with fixed contamination of the WEA sorting tray surface.*

**Administrative CSC 05:** *All waste evaluation operations SHALL be performed using only the designated sorting tray in each WEA.*

In support of the above Administrative CSCs, the WEA sorting tray is recognized as a Safety Feature, the Safety Functional Requirement being to provide containment of solids and liquids tipped onto its surface. Based on the permitted 20 liter volume of loose material that may be evaluated at one time, the WEA sorting tray must be sufficiently sized to accommodate this volume.

> **Safety Feature 01:** *WEA sorting tray (when being used for waste evaluation operations).*

> **Administrative CSC 06:** *Spillage of the content of any container received in a WEA onto any surface other than the designated sorting tray SHALL be recovered as soon as is practicable and prior to evaluation of the content of any additional containers. In the event that the spillage involved release of free liquids the NCS Organization SHALL be notified.*

The CSCs relevant to ensuring that any loose material would have a fissile concentration not exceeding the *Fissile Material Exhumation Limit* of 38 $g^{235}U/10L$ are indirectly credited in the risk assessment above. These CSCs are provided in References 14 and 17 and are not repeated here for brevity. However, these CSCs are listed in Section 3 for completeness.

### 2.4.3 Fissile Material is Transferred from a WEA to a WHA

#### 2.4.3.1 Discussion

The general aim of the waste evaluation operations is to identify and extract any uranium associated with the material content of an incoming CD that would be of concern from a NCS perspective. Identification of uranium is achieved by spreading/disassembling the material content of the CD across the surface of a sorting tray, and using hand-held gamma survey instruments and visual inspection to locate the uranium.

Any identified uranium of concern is collected and placed in an *Assay Container*, while the remaining portions of the evaluated material (i.e., the residual portion not containing any significant uranium) is gathered and loaded into a *Waste Container*. The *Assay Container* is sealed in a CD and transferred to a MAA for fissile content determination. The *Waste Container* is transferred to a WHA (i.e., is dispositioned as *NCS Exempt Material*).

In the event that *fissile material* is inadvertently loaded into a *Waste Container*, or an *Assay Container* is improperly dispositioned as *NCS Exempt Material*, the resultant transfer of *fissile material* to a downstream WHA could compromise the safety basis for WHA operations, potentially resulting in a criticality incident.

In the event that *fissile material* is not identified during a waste evaluation operation, the associated material would be loaded into a *Waste Container* and improperly dispositioned as *NCS Exempt Material*. The resultant inadvertent transfer of *fissile material* to the downstream WHA could compromise the safety basis for WHA operations, potentially resulting in a criticality incident.

#### 2.4.3.2 Risk Assessment

Inadvertent transfer of *fissile material* from a WEA to a WHA could potentially occur under the following circumstances:

- There is a failure to identify *fissile material* during waste evaluation operations; or
- Fissile material identified during waste evaluation operations is erroneously placed into a *Waste Container;* or
- The *Assay Container* loaded with *fissile material* is mislabeled as waste; or
- The *Assay Container* loaded with *fissile material* is misdirected to a WHA.

The initiating events identified above are addressed in this event sequence, with the exception of misdirection of an *Assay Container* to a WHA, which is addressed separately in Section 2.4.6.

The potential for a criticality incident due to erroneous transfer of *fissile material* to a WHA is considered very small, mainly because of the substantial quantity of *fissile material* required to present a credible criticality risk, relative to credible arisings.

An assessment of the risks presented by the transfer of *fissile material* from a HDP remediation area to a WHA is provided in Section 2.4.1 of Reference 17. This assessment concludes that several kg of *fissile material* would be necessary in a WHA to present a credible criticality risk, even when assuming conditions that are significantly more onerous than could credibly occur. A key consideration was that the uranium residues associated with buried wastes/contaminated soils generally represent a low-risk *fissile material.* However, waste evaluation operations in WEAs could serve to invalidate some of the 'low risk material' assumptions because the general aim of the WEA operations is to separate uranium from its associated waste matrix. For this reason, a criticality incident in a downstream WHA due to transfer of *fissile material* from a WEA cannot be considered incredible. Based on this assessment, it is seen that provision and use of appropriately calibrated gamma survey instruments to identify *fissile material* during waste evaluation operations is fundamental to preventing transfer of *fissile material* to a WHA. In addition, visual inspection is important because it affords further Defense-in-Depth (DinD) by ensuring that any items resembling items which could contain *fissile material* (e.g., a process filter) are identified and treated equivalently to *fissile materials.*

Establishing a low fissile content screening criteria of *1 g$^{235}$U in any contiguous 10 liter volume* will ensure that all residual materials that are transferred to a WHA will present no criticality safety concerns. The 1g$^{235}$U/10L *NCS Exempt Material* concentration limit is more than two orders of magnitude lower than the maximum safe fissile concentration for an infinite system comprising only $^{235}$U and water (11.6 g$^{235}$U/L, Table A-1), and a factor of forty smaller than the subcritical limit for an infinite system comprising only $^{235}$U and soil (4.0 g$^{235}$U/L, Appendix A). Thus, the 1g$^{235}$U/10L concentration limit affords an extremely large margin of safety.

Segregating identified *fissile materials* from non-*fissile materials* during waste evaluation, and packaging into clearly identifiable *Assay Containers* or *Waste Containers* (for fissile and non-*fissile materials*, respectively) is equally important to preventing the transfer of *fissile material* to a WHA.

The inevitable variability in the types of materials that may be received for evaluation necessitates the need to rely on human agency to fulfill the above requirements. Training is essential for any nuclear facility decommissioning activity and operations in a WEA are treated no differently. The WEA operators are knowledgeable, trained, and qualified to perform their assigned tasks, and fully recognize the importance in performing their tasks independently and according to procedure. This, combined with the following, ensures that the abovementioned controls would be at least unlikely to fail:

- Provision of simple and unambiguous procedures;
- The very low probability of encountering significant uranium concentrations; and
- The extremely large factor of safety (forty) between the *NCS Exempt Material* concentration limit (1g$^{235}$U/10L ) and the safety limit (4g$^{235}$U/L) for bulked material.

To ensure that the preventative measures established above provide sufficient risk reduction it is necessary to require that each individual procedure is independently performed by multiple (i.e., at least two) persons. It is also necessary to ensure that the multiple persons performing the radiological survey procedures use independent appropriately calibrated equipment.

The control reliability arguments presented above, combined with the use of multiple persons, ensures that this event sequence satisfies the DCP, because two unlikely concurrent failures would be required before a criticality accident could be possible.

#### 2.4.3.3 Summary of Risk Assessment

The following process upsets and conditions must be realized before a criticality accident due to inadvertent transfer of *fissile material* to a WHA could occur:

- Independent CSCs would have to be compromised to facilitate the transfer of *fissile material* to a WHA; and
- The combined $^{235}U$ mass associated with any *fissile material* erroneously transferred to a WHA would have to significantly exceed anticipated arisings.

The following additional criteria serve to further decrease the likelihood of a criticality accident:

- The erroneously transferred *fissile material* transferred would have to be:
  - of a high $^{235}U$ enrichment; and
  - suspended at optimum, or near optimum, concentration in an efficient (i.e., water) moderating medium; and
  - configured into a geometry that would favor a low critical mass system (i.e., assembled into a spherical or near spherical geometry.

#### 2.4.3.4 Safety Controls

The explicit CSCs relevant to preventing inadvertent transfer of *fissile material* to a WHA are established below. These CSCs are credited to provide the criticality safety barriers identified above. No additional practicable measures for further reducing criticality risk have been identified in the risk assessment. It is judged that the risks from criticality are as low as is reasonably achievable.

> **Administrative CSC 07:** *The content of each CD received in a WEA SHALL either be:*
>
> - *Evaluated for fissile material content following the WEA radiological survey and visual inspection procedures; or*
> - *SHALL be assumed to contain fissile material - in which case the CD SHALL be transferred to a MAA for radiological assay.*

**Administrative CSC 08:** *All WEA radiological survey and visual inspection procedures SHALL be independently followed by at least two qualified individuals. Equipment used by each qualified individual in support of these procedures SHALL be independent.*

**Administrative CSC 09:** *Material designated for fissile material content evaluation SHALL be spread/disassembled on the surface of the WEA sorting tray and radiologically surveyed. In the event that the fissile concentration of any region of the surveyed material exceeds 1 g $^{235}U$ in any contiguous 10 liter volume, the material at those locations SHALL be extracted and containerized in a labeled and lidded Assay Container. The remaining portion(s) of the surveyed material may be loaded into a Waste Container and dispositioned as NCS Exempt Material.*

<u>*Notes:*</u>

1. *Prior to performing radiological surveys:*
   a. *Loose materials SHALL be spread over the surface of the WEA sorting tray to create a layer of material with depth as small as practicable; and*
   b. *Objects with interior spaces SHALL be disassembled/cut to the extent required to survey all interior spaces, unless the intervening material is accounted for in the radiological survey equipment calibration basis.*
2. *Any materials which cannot be verified to contain less than 1 g $^{235}U$ in any contiguous 10 liter volume (e.g., due to accessibility constraints or equipment calibration issues) SHALL be assumed to be fissile material (i.e., containerized in a labeled and lidded Assay Container).*

In support of the above Administrative CSCs, equipment used in support of WEA radiological surveys are designated as Safety Related Equipment, the Safety Functional Requirement being to measure gamma radiation emission from $^{235}U$ nuclides, which will permit estimation of $^{235}U$ content when properly calibrated and used in accordance with applicable procedures.

**Safety Related Equipment 01:** *Instruments used in support of WEA radiological surveys (when used in support of a CSC).*

**Administrative CSC 10:** *Radiological surveys performed in support of WEA CSCs SHALL use only equipment that is approved and appropriately calibrated to account for potential under-reading due to the effect of credible variation in uranium distribution, particle size and attenuation of the photon intensity within the surrounding material.*

**Administrative CSC 11:** *In conjunction with WEA radiological surveys, all materials deposited on a WEA sorting tray SHALL be visually inspected. In the event that any items are identified to potentially contain fissile material (e.g., a process filter is identified), the item(s) SHALL be extracted and containerized in an Assay Container.*

### 2.4.4 Excess Fissile Material is Transferred from a WEA to a MAA

#### 2.4.4.1 Discussion

The general aim of the waste evaluation operations is to identify and extract any uranium associated with the material content of an incoming CD that would be of concern from a NCS perspective. Identification of uranium is achieved by spreading/disassembling the material content of the CD across the surface of a sorting tray, and using hand-held gamma survey instruments and visual inspection to locate the uranium.

Any identified uranium of concern is collected and placed in an *Assay Container*, while the remaining portions of the evaluated material (i.e., the residual portion not containing any significant uranium) is gathered and loaded into a *Waste Container*. The *Assay Container* is sealed in a CD and transferred to a MAA for fissile content determination. The *Waste Container* is transferred to a WHA (i.e., is dispositioned as *NCS Exempt Material*).

In the event that too much *fissile material* is loaded into a single *Assay Container*, subsequent transfer of the *Assay Container* to a MAA could result in a criticality incident during transit or on receipt in a MAA.

#### 2.4.4.2 Risk Assessment

Overloading a single *Assay Container* with *fissile material* could potentially occur under the following circumstances:

- There is a failure to identify *fissile material* during waste evaluation operations; or
- Fissile material recovered from multiple incoming CDs are loaded into the same *Assay Container*.

The potential for overloading a single *Assay Container* due to failure to identify *fissile material* during waste evaluation operations is addressed in Section 2.4.3.2. Consequently all of the controls established in Section 2.4.3.4 are also important to this event sequence. These controls are effective in preventing a criticality incident due to overloading a single *Assay Container* because of failing to identify *fissile material* during waste evaluation operations.

The potential for overloading a single *Assay Container* due to batching material from multiple incoming CDs is prevented by requiring that the content of only one incoming CD is loaded into a single *Assay Container*, no matter how small in volume that material may be. Because some evaluated materials may comprise items resembling large volume containers exhumed from a burial pit or other bulky objects with large volume, it is considered necessary to limit the volume of all *Assay Containers* to a maximum 20 liters (equivalent to the volume of a nominal 5 gallon container).

As previously noted, the types of operations performed in a WEA necessitates the need to rely on human agency to fulfill the above requirements. Training is essential for any nuclear facility decommissioning activity and operations in a WEA are treated no differently. The WEA operators are knowledgeable, trained, and qualified to perform their assigned tasks, and fully recognize the importance in performing their tasks independently and according to procedure. This, combined with the following, ensures that the abovementioned controls would be at least unlikely to fail:

- Provision of simple and unambiguous procedures;
- The very low probability of encountering significant uranium concentrations; and
- The very large factor of safety (ten) between the *Fissile Material Exhumation Limit* (38g$^{235}$U/10L ) and the 350g$^{235}$U container mass safety limit for receipt in a downstream MAA.

To ensure that the preventative measures established above provide sufficient risk reduction it is necessary to require that each individual procedure is independently performed by multiple (i.e., at least two) persons. The control reliability arguments presented above, combined with the use of multiple persons, ensures that this event sequence satisfies the DCP, because two unlikely concurrent failures would be required before a criticality accident could be possible.

#### 2.4.4.3 Summary of Risk Assessment

The following process upsets and conditions must be realized before a criticality accident due to inadvertent transfer of *fissile material* to a WHA could occur:

- Independent CSCs would have to be compromised to facilitate:
  - loading of material from more than one CD into a single *Assay Container*; and/or
  - Loading more than 20 liters of loose evaluated material into a single *Assay Container*; and
- The combined $^{235}$U mass associated with any single *Assay Container* would have to significantly exceed anticipated arisings.

The following additional criteria serve to further decrease the likelihood of a criticality accident:

- The excess *fissile material* associated with the overloaded *Assay Container* would have to be:
  - of a high $^{235}$U enrichment; and
  - suspended at optimum, or near optimum, concentration in an efficient (i.e., water) moderating medium; and
  - configured into a geometry that would favor a low critical mass system (i.e., assembled into a spherical or near spherical geometry.

#### 2.4.4.4 Safety Controls

The explicit CSCs relevant to preventing overloading of a single *Assay Container* with *fissile* *material* are established below. These CSCs are credited to provide the criticality safety barriers identified above. No additional practicable measures for further reducing criticality risk have been identified in the risk assessment. It is judged that the risks from criticality are as low as is reasonably achievable.

**Administrative CSC 03:** *All waste evaluation operations SHALL be independently observed for adherence to procedure by at least one individual.*

**Administrative CSC 12:** *Each Assay Container loaded in a WEA SHALL be limited to:*

- *Materials originating from only a single CD; and*
- *A maximum content of 20 liters of loose material or one single item (in the event that the evaluated single item has a volume exceeding 20 liters).*

### 2.4.5 There is an Accumulation of Fissile Material within a MAA

#### 2.4.5.1 Discussion

*Fissile materials* loaded into *Assay Containers* in WEAs will be radiologically counted in a MAA to establish $^{235}U$ mass content, as described in Section 1.4. In addition, other solid wastes generated from HDP remediation areas and the site WTS may be directly transferred to a MAA for assay.

In the event that multiple CDs are present in a MAA at one time it is possible that neutron interaction between the *fissile materials* associated with the CDs could occur, presenting a criticality risk.

#### 2.4.5.2 Risk Assessment

The potential for a criticality accident due to congregation of loaded CDs in a MAA is generically assessed in Reference 18. Based on the assessment in Reference 18, there is no restriction on allowing multiple CDs to reside in a MAA because the geometry and design of CDs ensures their safety when arranged in any unstacked configuration. However, to ensure safe interaction with *Assay Containers* outside the environs of a CD, it is necessary to limit the number of *Assay Containers* that may be handled outside of a CD to only one at a time.

As manual nature of operations in a MAA necessitates the need to rely on human agency to fulfill the above requirement. Training is essential for any nuclear facility decommissioning activity and operations in a MAA are treated no differently. The MAA operators are knowledgeable, trained, and qualified to perform their assigned tasks, and fully recognize the importance in performing their tasks independently and according to procedure. This, combined with the provision of simple and unambiguous procedure ensures that the abovementioned control would be at least unlikely to fail.

To ensure that the preventative measure established above provides sufficient risk reduction it is necessary to require that the associated procedure is independently observed by at least one other qualified individual. The control reliability argument presented above, combined with the use of multiple persons, ensures that this event sequence satisfies the DCP, because two unlikely concurrent failures would be required before a criticality accident could be possible.

#### 2.4.5.3 Summary of Risk Assessment

The following process upsets and conditions must be realized before a criticality accident due to an accumulation of *fissile material* within a MAA could occur:

- Independent CSCs would have to fail to prevent limiting the number of *Assay Containers* that may be handled outside of a CD to only one at a time; and
- The combined $^{235}U$ mass associated with any single *Assay Container* would have to significantly exceed anticipated arisings.

The following additional criteria serve to further decrease the likelihood of a criticality accident:

- The *fissile material* associated with *Assay Containers* would have to be:
  - of a high $^{235}U$ enrichment; and
  - suspended at optimum, or near optimum, concentration in an efficient (i.e., water) moderating medium; and
  - configured into a geometry that would favor a low critical mass system (i.e., assembled into a spherical or near spherical geometry.

### 2.4.5.4 Safety Controls

The explicit CSCs relevant to preventing an accumulation of *fissile material* within a MAA are established below. These CSCs are credited to provide the criticality safety barriers identified above. No additional practicable measures for further reducing criticality risk have been identified in the risk assessment. It is judged that the risks from criticality are as low as is reasonably achievable.

**Administrative CSC 13:** *All MAA Assay Container handling operations SHALL be independently observed for adherence to procedure by at least one individual.*

**Administrative CSC 14:** *The number of assay containers that may outside the environs of a CD SHALL be limited to a maximum of only one at any time.*

### 2.4.6 Low Fissile Mass is Assigned to an Assay Container following Assay

#### 2.4.6.1 Discussion

As described in Section 1.4 and noted elsewhere, all *fissile materials* loaded into *Assay Containers* in WEAs will be radiologically counted at a MAA to establish $^{235}U$ mass content. In addition, other solid wastes generated from HDP remediation areas and the site WTS may be directly transferred to a MAA for assay. Following radiological counting, the total $^{235}U$ content established for the *Assay Container* is used to determine the disposition of the container, as follows:

- In the event the total $^{235}U$ content of the *Assay Container* is estimated to be less than or equal to 15 g$^{235}U$, the *Assay Container* is declared a *Waste Container*, removed from the MAA and dispositioned as *NCS Exempt Material.*
- In the event the total $^{235}U$ content of the *Assay Container* is estimated to be greater than 15 g$^{235}U$, the *Assay Container* is declared a *Fissile Material Container,* marked with a unique identification number and accompanied by paperwork describing the fissile contents (i.e., a description of the waste and its total estimated $^{235}U$ gram content). The labeled *Fissile Material Container* is sealed in a CD (if the *Fissile Material Container* is not actually a CD), removed from the MAA, and transferred to a CDRA for staging or a FMSA for storage*.

In the event that *Assay Containers* are erroneously ascribed a low $^{235}U$ content, the containers could be improperly dispositioned as *Waste Containers* (for mass estimates $\leq$ 15g$^{235}U$), or placed into a CDRA/FMSA resulting in excess fissile mass in a CD, or less restrictive spacing being applied than would be appropriate for the actual fissile mass of the CD. Realization of these conditions could compromise the safety basis for the safety of *Waste Containers* in a WHA, or could erode the safety margin for CDs staged in a CDRA or stored in a FMSA.

#### 2.4.6.2 Risk Assessment

As noted above, the disposition of containerized *fissile materials* is wholly dependent on their ascribed $^{235}U$ mass content, which is established by radiological counting at a MAA. The following errors could lead to an *Assay Container* holding higher fissile mass than its assigned $^{235}U$ mass content:

- HRGS assay equipment underestimating the fissile mass in a container.
- Incorrectly labeling a container such that the assigned mass is less than the actual mass established by HRGS assay.

Assigning an underestimate of fissile mass would only be significant if it led to improper disposition of a container as *NCS Exempt Material* when the actual fissile content warranted

* Note that future disposition of *Fissile Material Containers* in any FMSA is not addressed in this NCSA and will be covered under documented case-specific NCSAs.

criticality controls, or if it resulted in improper CD handling during transit or improper staging/storage in a CDRA/FMSA.

Improper Disposition of *Assay Containers* as *Waste Containers*

The potential for improper disposition of *Assay Containers* as *Waste Containers* (i.e., as *NCS Exempt Material*) is limited because the fissile mass threshold for this declaration is high (15 g$^{235}$U) relative to the expected fissile content of the vast majority of *Assay Containers* (i.e., up to only gram quantities of *fissile material*).

Based on the assessment provided in Section 2.4.10.2 of Reference 17, it is clear that CDs loaded with materials exhumed from HDP remediation areas with known burials (i.e., burial pits) have the greatest potential for significant $^{235}$U loading. However, the site burial logs indicate that the vast majority of the 15,000 waste consignments to burial pits were assigned a nominal 1 g$^{235}$U inventory, based on the limit of detection capability (Ref. 6). Only a very small number of waste consignments (ten) involved non-trivial $^{235}$U loadings. Thus, the potential for improperly dispositioning *Assay Containers* as *Waste Containers* is considered small. However, waste evaluation operations in WEAs could invalidate some of these low $^{235}$U loading assumptions because the general aim of the WEA operations is to identify and collect only uranium in *Assay Containers*.

In summary, even though the potential for erroneous disposition of high fissile content *Assay Containers* as *Waste Containers* is small, a criticality incident in a downstream WHA cannot be considered incredible. For this reason, the provision and efficacy of the HRGS assay equipment, in conjunction with correct use of the equipment and proper transcribing of assay results, is integral to the safety basis of waste accumulation in a downstream WHA. These considerations make it necessary to recognize the HRGS assay equipment as Safety Related Equipment and to establish Administrative CSCs to ensure correct use of the equipment and proper transcribing of assay results.

Improper Handling, Transit, or Storage of CDs

If the $^{235}$U mass content assigned to a *Fissile Material Container* resulted in improper handling during transit or improper staging/storage in a CDRA/FMSA (e.g., less restrictive spacing being applied than would be appropriate for the actual fissile mass), a potential criticality hazard could occur due to excessive neutron interaction.

Improper handling during transit between a MAA and a CDRA/FMSA would require the *CD* to hold > 350 g$^{235}$U and erroneously be assigned a fissile content < 350 g$^{235}$U, resulting in the potential for excessive neutron interaction with other CDs in transit or storage (refer to Reference 18 for justification of these limits).

Improper storage in a CDRA/FMSA would require:

- the CD to hold > 225 g$^{235}$U and erroneously be assigned a fissile content < 125 g$^{235}$U, resulting in a 'batching' (i.e., repacking) upset in a CDRA (refer to Reference 16 for justification), or

- the CD to hold > 350 g$^{235}$U <u>and</u> erroneously be assigned a fissile content < 350 g$^{235}$U, resulting in a neutron interaction upset in a FMSA due to less spacing being applied than would be appropriate for the actual fissile mass (refer to Reference 13 for justification).

The potential for a criticality incident due to improper handling or staging/storage of a CD with an erroneously ascribed fissile content is considered very small, based on the unlikelihood of encountering the chronic CD fissile loading required for a criticality incident. Nevertheless, the importance of accuracy of measurement and assignment of fissile mass estimates is integral to the safety basis of *fissile material* handling, staging, and storage. Therefore, it is necessary to establish requirements to ensure that:

- *Assay Containers* received at a MAA are assayed using appropriately calibrated assay equipment to establish a $^{235}$U mass content estimate; and
- Assay results are properly transcribed using a label listing the container identification number, a description of contents, and the estimated $^{235}$U mass content.

The nature of MAA operations necessitates the need to rely on human agency to fulfill the above requirements. Training is essential for any nuclear facility decommissioning activity and operations in a MAA are treated no differently. The WEA operators are knowledgeable, trained, and qualified to perform their assigned tasks, and fully recognize the importance in performing their tasks independently and according to procedure. These considerations, combined with the following, ensures that the abovementioned controls would be at least unlikely to fail:

- Provision of simple and unambiguous procedures;
- The very low probability of encountering a significant $^{235}$U mass in any container; and
- The large margin of safety between the maximum anticipated arisings (a few tens of grams $^{235}$U per container (refer to Section 2.3 for justification) and the safety limit for downstream operations (i.e., at least 225 g$^{235}$U per container).

To ensure that the preventative measures established above provide sufficient risk reduction it is necessary to require that each individual procedure is independently performed by multiple (i.e., at least two) persons. It is also necessary to ensure that the multiple persons performing the assay procedures use independent appropriately calibrated equipment or that the equipment is functionally checked between use.

The control reliability arguments presented above, combined with the use of multiple persons, ensures that this event sequence satisfies the DCP, because two unlikely concurrent failures would be required before a criticality accident could be possible.

### 2.4.6.3 Summary of Risk Assessment

The following process upsets and conditions must be realized before a criticality accident due to erroneously ascribing a low $^{235}U$ content to *Assay Containers* could occur:

- Independent CSCs would have to be compromised to facilitate erroneously ascribing a low $^{235}U$ content to *Assay Containers*; and
- The combined $^{235}U$ mass associated with the erroneously ascribed container(s) would have significantly exceed anticipated arisings; and
- The uranium associated with the erroneously ascribed container(s) would have to be:
  - of a high $^{235}U$ enrichment; and
  - suspended at optimum, or near optimum, concentration in an efficient (i.e., water) moderating medium; and
  - configured into a geometry that would favor a low critical mass system (i.e., assembled into a spherical or near spherical geometry.

### 2.4.6.4 Safety Controls

The explicit CSCs relevant to ensuring assay of *Assay Containers*, correct use of the assay equipment, and to ensure proper transcribing of assay results, are established below. These CSCs are credited to provide the criticality safety barriers identified above. No additional practicable measures for further reducing criticality risk have been identified in the risk assessment. It is judged that the risks from criticality are as low as is reasonably achievable.

> **Administrative CSC 15:** *Assay Containers received at a MAA SHALL be independently assayed by at least two qualified individuals using the HRGS assay equipment and following the Container Assay Procedure, to establish at least two independent* $^{235}U$ *mass content estimates.*

**Administrative CSC 16:** *The following Container Assay Procedure SHALL be followed to obtain a single $^{235}U$ mass content estimate for any Assay Container received at a MAA:*

1) *Pre-assay checks of the assay equipment SHALL be conducted to confirm that the equipment is properly functioning;*
2) *The Assay Container SHALL be placed into the proper counting position in the assay equipment;*
3) *A calibration routine SHALL be selected for the assay equipment that is appropriate to the size, volume and content of the Assay Container;*
4) *Radiological counting SHALL be initiated;*
5) *The results of the radiological counting SHALL be examined to establish the $^{235}U$ mass content estimated for the Assay Container;*
6) *Post-assay checks of the assay equipment SHALL be conducted to confirm that the equipment is properly functioning; and*
7) *In the event the pre-assay and post-assay checks are confirmed acceptable and consistent, the assay result may be regarded as valid. In the event the pre-assay and post-assay checks are not confirmed acceptable or consistent, the assay result SHALL be regarded as invalid and discarded.*

*Notes:*

1. *In the event that the available MAA assay equipment calibration routines are not valid due to the material properties of the Assay Container, the subject container SHALL be interim stored in a CDBS.*

**Administrative CSC 17:** *The Post-assay check of the most recent container assay may be used to satisfy the Pre-assay check requirement in step (1) of the Container Assay Procedure, provided that the Post-assay check of the most recent container assay was conducted during the same operations shift.*

**Administrative CSC 18:** *The Pre-assay and Post-assay check requirements in steps (1) and (6) of the Container Assay Procedure may be disregarded (i.e., skipped) provided that the qualified individuals conducting the container assays do not use the same HRGS equipment (i.e., use different equipment).*

**Administrative CSC 19:** *Following assay of an Assay Container at a MAA by at least two qualified individuals working independently, the independent $^{235}U$ mass content estimates established SHALL be compared. In the event of a large deviation between the $^{235}U$ mass content estimates (i.e., >20% difference in mass), the Assay Container SHALL be re-assayed following the Container Assay Procedure until the $^{235}U$ mass content estimates are consistent (i.e., <20% difference in mass).*

**Administrative CSC 20:** *The consistent $^{235}U$ mass content estimates established by the qualified individuals that followed the Container Assay Procedure SHALL be assigned to the Assay Container using a label listing the container identification number, a description of contents and the estimated $^{235}U$ mass content. The accuracy of the data and information recorded on the label SHALL be confirmed by at least two qualified individuals before the ascribed $^{235}U$ mass content is regarded as valid.*

In support of the above Administrative CSC, MAA monitoring equipment is designated as Safety Related Equipment, the Safety Functional Requirement being to provide $^{235}U$ gram content estimates of items presented for characterization, consistent with the calibration routine selected.

**Safety Related Equipment 02:** *MAA monitoring equipment used to establish the $^{235}U$ content of Assay Containers (when being used for the purpose of criticality control).*

## 2.4.7 High Fissile Mass Content is Assigned to an Assay Container following Assay

### 2.4.7.1 Discussion

As previously described, the $^{235}U$ content established for each *Assay Container* radiologically counted in a MAA is used to determine the disposition of the container. In the event that the total $^{235}U$ content established for the *Assay Container* is exceptionally high (i.e., exceeds 350 $g^{235}U$) subsequent handling of the container at the MAA and/or transit of the container to other functional areas could result in an unanalyzed condition, or under an extreme high fissile loading condition (i.e., container mass exceeds 760 $g^{235}U$), could potentially result in a criticality incident.

### 2.4.7.2 Risk Assessment

Prior sections of this NCSA have assessed the potential for CDs to contain high fissile content and concluded that this potential is small.

In-situ radiological survey requirements established as CSCs in References 14 and 17 will ensure that exhumed *fissile materials* will not contain high fissile loading, and thus, that each loaded CD will not contain >350 $g^{235}U$, except in exceptional situations where special evaluation by the NCS Organization will be required and tailored controls may be employed*. However, it is possible that items resembling large intact containers or other bulky items could be exhumed from a HDP remediation area and, due to their characteristics, could contain high fissile loading which may not be revealed by in-situ radiological surveys. This potential is assessed below.

Based on the assessment provided in Section 2.4.10.2 of Reference 17, it is seen that even the ten highest inventory items consigned to the site burial grounds, combined, do not contain sufficient fissile mass to present a criticality hazard, even under idealized geometry, concentration, moderation, and reflection conditions. This is also sustained if their recorded $^{235}U$ mass content estimates are assumed to be underestimated by 100% (refer to Section 2.4.3.2 of Reference 17 for details). Based on these arguments, the potential for encountering a CD with a high fissile loading is very small.

In the event that the mass content of any *Assay Container* is established to exceed 350 $g^{235}U$following radiological counting at a MAA, subsequent transit of the *Assay Container* within a CD would represent an unanalyzed condition, because the safety basis for *fissile material* transit (refer to Reference 18) is founded on a limiting CD mass of 350 $g^{235}U$. Furthermore, in the event that the mass content of any *Assay Container* is established to exceed 760 $g^{235}U$ following radiological counting, further handling or movement of the *Assay*

* Assessment of non-exceptional conditions is outside the scope of this NCSA and will be addressed in case specific evaluations. Administrative CSCs established in this NCSA and other NCSAs ensure that any situation constituting an exceptional condition will be evaluated by the NCS Organization prior to taking further action.

*Container* would represent an unanalyzed condition, and under extreme fissile loading conditions, could potentially result in a criticality incident. These considerations make it necessary to establish the following requirements:

- The labeled $^{235}U$ mass content estimate ascribed to an *Assay Container* following radiological counting at a MAA shall be verified to not exceed 350 g$^{235}U$ prior to allowing any handling or movement of the *Assay Container*; and
- In the event that the $^{235}U$ mass content ascribed to an *Assay Container* exceeds 350 g$^{235}U$ all MAA operations shall cease and shall not resume until the NCS Organization has been notified and has approved resumption of operations.

These precautions will prevent handling and/or transit of an *Assay Container* with a high $^{235}U$ mass content.

The nature of MAA operations necessitates the need to rely on human agency to fulfill the above requirements. Training is essential for any nuclear facility decommissioning activity and operations in a MAA are treated no differently. The WEA operators are knowledgeable, trained, and qualified to perform their assigned tasks, and fully recognize the importance in performing their tasks independently and according to procedure. These considerations, combined with the following, ensures that the abovementioned controls would be at least unlikely to fail:

- Provision of simple and unambiguous procedures;
- The very low probability of encountering a significant $^{235}U$ mass in any container; and
- The large margin of safety between the maximum anticipated arisings (a few tens of grams $^{235}U$ per container (refer to Section 2.3 for justification) and the safety limit for CD handling and transit (350 g$^{235}U$ per CD).

To ensure that the preventative measures established above provide sufficient risk reduction it is necessary to require that each individual procedure is independently performed by multiple (i.e., at least two) persons.

The control reliability arguments presented above, combined with the use of multiple persons, ensures that this event sequence satisfies the DCP, because two unlikely concurrent failures would be required before a criticality accident could be possible.

It is also noted that this event sequence is further protected for CDs received from a WEA because WEA controls ensure that *Assay Containers* loaded in a WEA would not likely contain >350 g$^{235}U$ (refer to Section 2.4.4.4 for details). These CDs are expected to represent the vast majority of CDs that will be received in a MAA because it is expected to be infrequent that a CD would be directed to a MAA without prior evaluation of its content in a WEA. Examples may include bulky objects difficult to dismantle, WTS solids, and CDs containing potentially hazardous material.

#### 2.4.7.3 Summary of Risk Assessment

The following process upsets and conditions must be realized before a criticality accident due to handling of an *Assay Container* with an exceptionally high fissile content could occur:

- Independent CSCs would have to be compromised to facilitate handling or movement of an *Assay Container* with exceptionally high fissile content; and
- The uranium content of the *Assay Container* would have to be of a high $^{235}U$ enrichment; and
- The uranium content of the *Assay Container* would have to be suspended at optimum, or near optimum, concentration in an efficient (i.e., water) moderating medium; and
- The uranium content of the *Assay Container* would have to be configured into a geometry that would favor a low critical mass system (i.e., assembled into a spherical or near spherical geometry); and
- Non fissile and non hydrogenous elements would have to be absent, or at least present in small quantities (otherwise these constituents would result in dilution and parasitic neutron absorption).

#### 2.4.7.4 Safety Controls

The explicit CSCs relevant to preventing handling of an *Assay Container* with an exceptionally high fissile content are established below. These CSCs are credited to provide the criticality safety barriers identified above. No additional practicable measures for further reducing criticality risk have been identified in the risk assessment. It is judged that the risks from criticality are as low as is reasonably achievable.

> **Administrative CSC 21:** *At least two qualified individuals SHALL confirm that the labeled $^{235}U$ mass content estimate ascribed to an Assay Container following radiological counting at a MAA does not exceed 350 g $^{235}U$ prior to allowing any handling or movement of the Assay Container.*

> **Administrative CSC 22:** *In the event that the $^{235}U$ mass content ascribed to an Assay Container exceeds 350 g $^{235}U$ all MAA operations SHALL cease and SHALL NOT resume until the NCS Organization has been notified and has approved resumption of operations.*

As noted in Section 2.4.7.3, the controls established in Section 2.4.4.4 are also relevant to this event sequence. These controls are listed below.

> **Administrative CSC 03:** *All waste evaluation operations SHALL be independently observed for adherence to procedure by at least one individual.*

**Administrative CSC 12:** *Each Assay Container loaded in a WEA SHALL be limited to:*

- *Materials originating from only a single CD; and*
- *A maximum content of 20 liters of loose material or one single item (in the event that the evaluated single item has a volume exceeding 20 liters).*

# 3.0 SUMMARY OF CRITICALITY SAFETY CONTROLS

## 3.1 Criticality Safety Parameters

The extent of control of each of the various criticality safety parameters introduced in Section 3.1 is summarized in Table 3-1.

Table 3-1 Criticality Safety Parameters

| Nuclear Parameter | Controlled (Y/N) | Basis | Reference |
|---|---|---|---|
| Geometry | N | The safety assessment of waste evaluation and assay activities does not credit geometry. | N/A |
| Interaction | N | Upsets resulting in the potential to result in unanalyzed neutron interaction between *fissile materials* in a WAA have been assessed in this NCSA and preventative Administrative CSCs have been identified. | Section 2.4.5 |
| Mass | Y | The safety assessment of waste evaluation and assay activities establishes numerous administrative CSCs where mass control is employed. | Section 2.4.1<br>Section 2.4.2<br>Section 2.4.3<br>Section 2.4.4<br>Section 2.4.5<br>Section 2.4.6<br>Section 2.4.7 |
| Isotopic / Enrichment | N | The safety assessment of waste evaluation and assay activities is conservatively based on subcritical limits derived for uranium with 100 wt.% $^{235}U/U$ enrichment. | N/A |
| Moderation | N | The safety assessment of waste evaluation and assay activities does not credit moderation control. | N/A |
| Density | N | The safety assessment of waste evaluation and assay activities is conservatively based on subcritical limits derived for uranium metal at maximum theoretical density. | N/A |
| Heterogeneity | N | The safety assessment of waste evaluation and assay activities is conservatively based on subcritical limits derived for homogeneous uranium-$H_2O$ mixtures (with 100 wt.% $^{235}U/U$ enrichment), for which subcritical limits are smaller than equivalent heterogeneous uranium-$H_2O$ mixtures.<br><br>The potential impact of $^{235}U$ mass underestimation during radiological survey/assay in a WEA/MAA due to the potential variation in uranium distribution and particle size is addressed in Sections 2.4.3 and 2.4.6. | Section 2.4.3<br>Section 2.4.6 |

| Nuclear Parameter | Controlled (Y/N) | Basis | Reference |
|---|---|---|---|
| Neutron Absorbers | N | The safety assessment of waste evaluation and assay activities does not credit fixed neutron absorbers. | N/A |
| Reflection | N | The safety assessment of waste evaluation and assay activities conservatively uses subcritical limits based on full (i.e., 30 cm) thickness close fitting water reflection conditions. This assumption is considered bounding. | N/A |
| Concentration | Y | Upsets resulting in the potential to inadvertently classify *fissile material* as *NCS Exempt Material*, on the basis of its $^{235}U$ concentration, have been assessed in this NCSA and preventative Administrative CSCs have been identified. | Section 2.4.3<br>Section 2.4.6 |
| Volume | Y | The safety assessment of waste evaluation and assay activities credits administrative CSCs that ensure that loose materials evaluated in a WEA will be limited to a maximum volume of 20 liters at one time. This safety assessment of waste evaluation and assay activities also credits administrative CSCs that ensure that loose *fissile materials* loaded into an *Assay Container* following evaluation in a WEA will be limited to a maximum volume of 20 liters. | Section 2.4.1<br>Section 2.4.2<br>Section 2.4.4 |

Source: Original

## 3.2 Criticality Safety Controls and Defense-in-Depth Controls

This section provides a schedule of Systems, Structures, and Components (SSCs), CSCs, and DinD controls that have been established as important to safety in the risk assessment of waste evaluation and assay activities. The SSCs, CSCs, and DinD controls are numbered sequentially according to their identification in Section 2.4 of this document. Note that when SSCs, CSCs, and DinD controls captured in an NCSA are used in other documents (including other NCSAs), they are referenced using the numeric identifier from the originating NCSA and proceeded by the NCSA document number. For example, other documents citing the first CSC captured in this NCSA use the following reference; *NSA-TR-09-09 Administrative CSC 01.*

### 3.2.1 Systems, Structures, and Components

The following SSCs have been recognized as important to ensuring the criticality safety of waste evaluation and assay activities. The SSCs are identified as Safety Features (passive function) and Safety Related Equipment (active function). Based on their safety designation, the equipment listed in this Section are integral to the HDP safety case and HDP operations would not be able to continue in their absence.

**Safety Feature 01:** *WEA sorting tray (when being used for waste evaluation operations).*

**Safety Related Equipment 01:** *Instruments used in support of WEA radiological surveys (when used in support of a CSC).*

**Safety Related Equipment 02:** *MAA monitoring equipment used to establish the $^{235}U$ content of Assay Containers (when being used for the purpose of criticality control).*

### 3.2.2 Criticality Safety Controls

The following CSCs have been recognized as important to ensuring the criticality safety of waste evaluation and assay activities.

**Administrative CSC 01:** *The volume of loose material evaluated at any one time on a WEA sorting tray SHALL be limited to a maximum of 20 liters (equivalent to the volume of a nominal 5 gallon container).*

Notes:

1. *This CSC only applies to loose materials (e.g., the material content of exhumed intact containers) and does not apply to bulky objects such as a piece of equipment.*

**Administrative CSC 02:** *In the event of discovery of bottles containing liquids or significant quantities of uranium products such as pieces of metal, pellets/pellet fragments or powders, operations in the affected area SHALL be curtailed and SHALL NOT resume without specialist advice from the NCS Organization.*

**Administrative CSC 03:** *All waste evaluation operations SHALL be independently observed for adherence to procedure by at least one individual.*

**Administrative CSC 04** *Prior to unloading the content of any CD in a WEA, the surface of the WEA sorting tray as well as the surrounding area SHALL be confirmed to be clear of any materials not contained in a Waste Container or CD.*

*Notes:*

1. *This CSC does not apply to any residual material associated with fixed contamination of the WEA sorting tray surface.*

**Administrative CSC 05:** *All waste evaluation operations SHALL be performed using only the designated sorting tray in each WEA.*

**Administrative CSC 06:** *Spillage of the content of any container received in a WEA onto any surface other than the designated sorting tray SHALL be recovered as soon as is practicable and prior to evaluation of the content of any additional containers. In the event that the spillage involved release of free liquids the NCS Organization SHALL be notified.*

**Administrative CSC 07:** *The content of each CD received in a WEA SHALL either be:*

- *Evaluated for fissile material content following the WEA radiological survey and visual inspection procedures; or*
- *SHALL be assumed to contain fissile material - in which case the CD SHALL be transferred to a MAA for radiological assay.*

**Administrative CSC 08:** *All WEA radiological survey and visual inspection procedures SHALL be independently followed by at least two qualified individuals. Equipment used by each qualified individual in support of these procedures SHALL be independent.*

**Administrative CSC 09:** *Material designated for fissile material content evaluation SHALL be spread/disassembled on the surface of the WEA sorting tray and radiologically surveyed. In the event that the fissile concentration of any region of the surveyed material exceeds 1 g $^{235}U$ in any contiguous 10 liter volume, the material at those locations SHALL be extracted and containerized in a labeled and lidded Assay Container. The remaining portion(s) of the surveyed material may be loaded into a Waste Container and dispositioned as NCS Exempt Material.*

Notes:

1. *Prior to performing radiological surveys:*
   a. *Loose materials SHALL be spread over the surface of the WEA sorting tray to create a layer of material with depth as small as practicable; and*
   b. *Objects with interior spaces SHALL be disassembled/cut to the extent required to survey all interior spaces, unless the intervening material is accounted for in the radiological survey equipment calibration basis.*
2. *Any materials which cannot be verified to contain less than 1 g $^{235}U$ in any contiguous 10 liter volume (e.g., due to accessibility constraints or equipment calibration issues) SHALL be assumed to be fissile material (i.e., containerized in a labeled and lidded Assay Container).*

**Administrative CSC 10:** *Radiological surveys performed in support of WEA CSCs SHALL use only equipment that is approved and appropriately calibrated to account for potential under-reading due to the effect of credible variation in uranium distribution, particle size and attenuation of the photon intensity within the surrounding material.*

**Administrative CSC 11:** *In conjunction with WEA radiological surveys, all materials deposited on a WEA sorting tray SHALL be visually inspected. In the event that any items are identified to potentially contain fissile material (e.g., a process filter is identified), the item(s) SHALL be extracted and containerized in an Assay Container.*

**Administrative CSC 12:** *Each Assay Container loaded in a WEA SHALL be limited to:*

- *Materials originating from only a single CD; and*
- *A maximum content of 20 liters of loose material or one single item (in the event that the evaluated single item has a volume exceeding 20 liters).*

**Administrative CSC 13:** *All MAA Assay Container handling operations SHALL be independently observed for adherence to procedure by at least one individual.*

**Administrative CSC 14:** *The number of assay containers that may outside the environs of a CD SHALL be limited to a maximum of only one at any time.*

**Administrative CSC 15:** *Assay Containers received at a MAA SHALL be independently assayed by at least two qualified individuals using the HRGS assay equipment and following the Container Assay Procedure, to establish at least two independent* $^{235}U$ *mass content estimates.*

**Administrative CSC 16:** *The following Container Assay Procedure SHALL be followed to obtain a single* $^{235}U$ *mass content estimate for any Assay Container received at a MAA:*

1) *Pre-assay checks of the assay equipment SHALL be conducted to confirm that the equipment is properly functioning;*
2) *The Assay Container SHALL be placed into the proper counting position in the assay equipment;*
3) *A calibration routine SHALL be selected for the assay equipment that is appropriate to the size, volume and content of the Assay Container;*
4) *Radiological counting SHALL be initiated;*
5) *The results of the radiological counting SHALL be examined to establish the* $^{235}U$ *mass content estimated for the Assay Container;*
6) *Post-assay checks of the assay equipment SHALL be conducted to confirm that the equipment is properly functioning; and*
7) *In the event the pre-assay and post-assay checks are confirmed acceptable and consistent, the assay result may be regarded as valid. In the event the pre-assay and post-assay checks are not confirmed acceptable or consistent, the assay result SHALL be regarded as invalid and discarded.*

*Notes:*

1. *In the event that the available MAA assay equipment calibration routines are not valid due to the material properties of the Assay Container, the subject container SHALL be interim stored in a CDBS.*

**Administrative CSC 17:** *The Post-assay check of the most recent container assay may be used to satisfy the Pre-assay check requirement in step (1) of the Container Assay Procedure, provided that the Post-assay check of the most recent container assay was conducted during the same operations shift.*

**Administrative CSC 18:** *The Pre-assay and Post-assay check requirements in steps (1) and (6) of the Container Assay Procedure may be disregarded (i.e., skipped) provided that the qualified individuals conducting the container assays do not use the same HRGS equipment (i.e., use different equipment).*

**Administrative CSC 19:** *Following assay of an Assay Container at a MAA by at least two qualified individuals working independently, the independent $^{235}U$ mass content estimates established SHALL be compared. In the event of a large deviation between the $^{235}U$ mass content estimates (i.e., >20% difference in mass), the Assay Container SHALL be re-assayed following the Container Assay Procedure until the $^{235}U$ mass content estimates are consistent (i.e., <20% difference in mass).*

**Administrative CSC 20:** *The consistent $^{235}U$ mass content estimates established by the qualified individuals that followed the Container Assay Procedure SHALL be assigned to the Assay Container using a label listing the container identification number, a description of contents and the estimated $^{235}U$ mass content. The accuracy of the data and information recorded on the label SHALL be confirmed by at least two qualified individuals before the ascribed $^{235}U$ mass content is regarded as valid.*

**Administrative CSC 21:** *At least two qualified individuals SHALL confirm that the labeled $^{235}U$ mass content estimate ascribed to an Assay Container following radiological counting at a MAA does not exceed 350 g $^{235}U$ prior to allowing any handling or movement of the Assay Container.*

**Administrative CSC 22:** *In the event that the $^{235}U$ mass content ascribed to an Assay Container exceeds 350 g $^{235}U$ all MAA operations SHALL cease and SHALL NOT resume until the NCS Organization has been notified and has approved resumption of operations.*

Based on the history of the site and site documentation (refer to Section 1.2.1.1), there is no expectation that fissile nuclides other than $^{235}U$ could exist within the site boundary. There is also no expectation that fissile liquids are present. These key assumptions are captured in the following CSCs:

**Administrative CSC 23:** *In the event that the presence of fissile nuclides other than $^{235}U$ are identified (e.g., as a result of radiological assay at a MAA), operations in the respective area SHALL cease and the NCS organization notified.*

**Administrative CSC 24:** *The NCS organization SHALL be notified in the event that any containerized liquids are encountered during waste evaluation operations in a WEA or radiological counting in a MAA.*

**Administrative CSC 25:** *In the event that any materials not originating from a HDP remediation area or the site WTS require evaluation/assay in a WEA/MAA, approval SHALL first be obtained from the NCS Organization.*

The following controls are relevant to ensuring that any loose received in a WEA for evaluation would have a fissile concentration not exceeding the *Fissile Material Exhumation Limit* of 38 $g^{235}U/10L$. These controls are captured in References 14 and 17 and are also important to this NCSA.

**NSA-TR-09-15 Safety Related Equipment 01:** *Instruments used in support of in-situ radiological surveys (when used in support of a CSC).*

**NSA-TR-09-15 Administrative CSC 01:** *All HDP remediation area in-situ radiological survey and visual inspection procedures SHALL be independently followed by at least two qualified individuals. Equipment used by each qualified individual in support of these procedures SHALL be independent.*

**NSA-TR-09-15 Administrative CSC 04:** *All operations related to removal of material from a HDP remediation area SHALL be independently observed for adherence to procedure by at least one individual.*

**NSA-TR-09-15 Administrative CSC 05:** *Radiological surveys performed in support of CSCs SHALL use only equipment that is approved and appropriately calibrated to account for potential under-reading due to the effect of credible variation in uranium distribution, particle size and attenuation of the photon intensity within the surrounding soil/waste medium.*

**NSA-TR-09-15 Administrative CSC 10:** *All HDP remediation areas SHALL be radiologically surveyed for fissile content prior to exhumation of any material. In the event that the fissile concentration of any region of the surveyed material exceeds 38* $g^{235}U$ *in any contiguous 10 liter volume, the soil/waste exhumation activities in the associated excavation area SHALL cease and the NCS Organization informed as soon as is practicable and at least before excavation operations in the subject area resume.*

**NSA-TR-09-15 Administrative CSC 14:** *All in-situ radiological survey, visual inspection and sampling procedures conducted in non-burial HDP remediation areas insignificantly contaminated with uranium SHALL be independently followed by at least two qualified individuals. Equipment used by the each qualified individual in support of these procedures SHALL be independent.*

**NSA-TR-09-15 Administrative CSC 15:** *The surface soils of all non-burial HDP remediation areas insignificantly contaminated with uranium SHALL be radiologically surveyed for fissile content prior to exhumation of any material. In the event that the fissile concentration of any region of the surveyed material exceeds 1 g $^{235}$U in any contiguous 10 liter volume, the subject HDP remediation area SHALL no longer be considered insignificantly contaminated with uranium and all remediation operations in the subject area SHALL be conducted in accordance with the generic HDP remediation area CSCs.*

**NSA-TR-09-15 Administrative CSC 16:** *In conjunction with in-situ radiological survey for fissile content, the surface soils of all non-burial HDP remediation areas insignificantly contaminated with uranium SHALL be visually inspected prior to exhumation of any material. In the event that any foreign items (i.e., items other than soils/rocks) are identified the subject HDP remediation area SHALL no longer be considered a non-burial area and all remediation operations in the subject area SHALL be conducted in accordance with the generic HDP remediation area CSCs.*

**NSA-TR-09-15 Administrative CSC 17:** *The soils of all non-burial HDP remediation areas insignificantly contaminated with uranium SHALL be SHALL be sampled to a depth equivalent to the anticipated excavation depth and inspected for buried waste and analyzed for $^{235}$U content. In the event that any foreign items (i.e., items other than soils/rocks) are identified in the sample cores, or the fissile concentration of any region of the sample cores exceeds 1 g $^{235}$U in any contiguous 10 liter volume, the subject HDP remediation area SHALL no longer be considered a non-burial HDP remediation area insignificantly contaminated with uranium and all remediation operations in the subject area SHALL be conducted in accordance with the generic HDP remediation area CSCs.*

**NSA-TR-09-08 Safety Related Equipment 01:** *Assay equipment used to classify sub-surface structure decommissioning debris as NCS Exempt Material (i.e., $\leq 1$ g $^{235}$U per 10 liter of debris) or Fissile Material (i.e., $> 1$ g $^{235}$U per 10 liter of debris) (when used in support of a CSC).*

**NSA-TR-09-08 Administrative CSC 01:** *At least two qualified individuals SHALL properly perform a surface assay of concrete debris prior to its excavation.*

**NSA-TR-09-08 Administrative CSC 02:** *Representative core samples SHALL be taken in and surrounding cracks, expansion joints, seams that were adjacent to legacy production walls, and layers of concrete that covered contaminated layers.*

**NSA-TR-09-08 Administrative CSC 03:** *All sub-surface structure decommissioning debris (i.e., concrete, crushed piping, surrounding soils, and septic system material) irrespective of its location SHALL be independently assayed prior to exhumation using independent assay devices. The enriched uranium concentration of the decommissioning debris SHALL be no greater than 1 gram $^{235}U$ in a 10 liter volume prior to bulking during or following exhumation. In addition, the enriched uranium concentration of the decommissioning debris classified as Fissile Material SHALL be no greater than 38 grams $^{235}U$ in a 10 liter volume prior to exhumation into a Field Container. Decommissioning debris with a concentration exceeding 38 grams $^{235}U$ in a 10 liter volume SHALL NOT be excavated without approval from the NCS Organization.*

**NSA-TR-09-08 Administrative CSC 09:** *Each assayed layer of sub-surface structure decommissioning debris (i.e., concrete, piping, surrounding soils, and septic system material) SHALL be exhumed cognizant of the maximum permitted cut depth established in the assay equipment calibration basis document. At least two qualified individuals SHALL ensure that the exhumed material is deposited in the excavation area and re-assayed if its exhumation results in the removal of a layer of material exceeding the maximum permitted cut depth.*

**NSA-TR-09-08 Administrative CSC 10:** *All reasonably practicable measures SHALL be taken to minimize the potential to exhume a layer of decommissioning debris exceeding the maximum permitted cut depth. Consideration should be given to:*

- *Controlling the excavation depth to a value smaller than the maximum permitted cut depth to provide margin;*
- *Employing excavation techniques and equipment that allow for an optimally controlled depth excavation; and*
- *Use of markers or other tools to provide indication when exceeding the maximum permitted cut depth.*

**NSA-TR-09-08 Administrative CSC 18:** *If a 10 liter segment in a particular intact pipe section is determined to contain a Fissile Material mass greater than 1 gram $^{235}U$ in a 10 liter volume of pipe and no greater than 38 grams $^{235}U$ in a 10 liter volume of pipe, then the segment SHALL be removed from the intact section and placed singly into a CD. At least two qualified individuals SHALL ensure each of these requirements is completed accurately. In addition, any intact segment of piping containing greater than 38 grams $^{235}U$ in a 10 liter volume SHALL NOT be placed into a CD without approval from the NCS Organization.*

### 3.2.3 Defense-in-Depth Controls

No DinD controls were identified in the risk assessment of waste evaluation and assay activities.

## 4.0 CONCLUSION

This criticality safety assessment demonstrates that activities related to waste evaluation and assay will be safe under all normal and foreseeable abnormal conditions. The assessment has determined that there are very large margins of safety under normal (i.e., expected) conditions and that there is considerable tolerance to faults under abnormal conditions.

All event sequences identified in the *What-if* analysis and assessed in this NCSA are shown to result in no criticality consequences, or are demonstrated to not have the potential to result in a criticality accident on account of:

- There being no credible sequence of events that could result in a criticality accident; or
- Demonstration that the event sequence complies with the DCP.

It is noted that all analysis is assessed against limits based on homogeneous $^{235}U$-$H_2O$ mixtures at optimum concentration (i.e., that the assessment is not reliant on moderation control). Consequently, there are no restrictions on the use of water for operations or for fire suppression.

## 5.0 REFERENCES

1. Buried Waste Characterization Plan for the Hematite Site, NRC Docket 070-0036, June 2006.

2. American National Standard for Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors, ANS-8.1, American Nuclear Society.

3. Atlantic Richfield Hanford Company (1969), Criticality Handbook Volume II, R D Carter, G R Kiel, K R Ridgway.

4. LA-10860-MS, Critical Dimensions of Systems Containing $^{235}U$, $^{239}Pu$, and $^{233}U$, 1986 Revision.

5. Selected Soil Areas Survey Plan For Westinghouse Electric Company Hematite, Missouri, C. Wiblin, May 2008.

6. Historical Site Assessment, Revision 0, DO-08-005.

7. Code of Federal Regulations, Title 10, Part 20.304, "Disposal by Burial in Soil," 1964.

8. UNC Internal Memorandum, F. G. Stengel to E. F. Sanders, "Burial of Material," May 14, 1965.

9. Hematite Burial Pit Log Books, Volumes 1 and 2, July 16, 1965, through November 6, 1970.

10. Westinghouse Electric Corporation LLC, Employee Interview Records, 2000 to 2008.

11. CE Internal Memorandum, J. Rode to Bill Sharkey, "The Hematite Burial Grounds," March 5, 1996.

12. NSA-TR-09-13, Rev. 0, NCSA of Water Collection and Treatment Activities at the Hematite Site, B. Matthews, May 2009.

13. NSA-TR-09-12, Rev. 0, NCSA of Fissile Material Storage at the Hematite Site, D. Vaughn, May 2008.

14. NSA-TR-09-08, Rev. 0, NCSA of Sub-Surface Structure Decommissioning at the Hematite Site, D. Vaughn, May 2009.

15. NC-09-001, Rev. 0, Hazards and Operability Study for Decommissioning Activities in Support of the Hematite Decommissioning Project, April 2009.

16. NSA-TR-09-11, Rev. 0, NCSA of Collared Drum Repack Area Operations at the Hematite Site, D. Vaughn, May 2009.

17. NSA-TR-09-15, Rev. 0, NCSA of Buried Waste Exhumation and Contaminated Soil Remediation at the Hematite Site, B. Matthews, May 2009.

18. NSA-TR-09-10, Rev. 0, NCSA of Collared Drum Staging, Buffer Storage and Transit at the Hematite Site, B. Matthews, May 2009.

19. NSA-TR-09-05 Rev. 0, Nuclear Criticality Safety Calculations to Support Criticality Parameter Sensitivity Studies for $^{235}$U Contaminated Soil/Wastes, April 2009.

20. NSA-CS-03, Rev. 0, Nuclear Criticality Safety Calculations for 350 g$^{235}$U Drum Arrays, D. Vaughn, April 2009.

# APPENDIX A

## Relevant Criticality Data

### CHARACTERISTICS OF BURIED WASTES AND CONTAMINATED SOILS

It is considered that the SNM residues associated with the buried wastes and contaminated structures and soils at the Hematite site is generally a low-risk *fissile material* because the form and associated matrix conditions are far from optimum for a neutron chain reaction. The characteristics of the wastes are completely dissimilar to those of an efficient fissile system. Efficient critical systems comprise:

- Efficient moderating materials;
- Uniform fissile / moderator mixtures;
- Concentrations of several tens of grams fissile per liter;
- Compact arrangements;
- Lack of voidage and diluents;
- Lack of neutron poisons; and
- Efficient reflectors or interaction with other *fissile material.*

As each parameter, or combination of parameters, moves away from the optimum the fissile mass required for a criticality increases. As this mass increases the probability that such a high fissile mass could have arisen and remained undetected decreases.

While criticality would be possible under highly non-optimum conditions (e.g., in low density, poisoned systems) the fissile mass needed for criticality (i.e., many kilograms) would far exceed credible quantities.

### Single Items

The presence of a sufficiently large fissile mass (i.e., ≥ a minimum critical mass) in a single accumulation could potentially result in a criticality. The maximum subcritical mass for $^{235}U$ in water is 760 g (Ref. 2), corresponding to optimum conditions of:

- Spherical homogeneous accumulation of $^{235}U$/ water;
- Full water moderation (i.e., full density water, no poisons, diluents, voidage etc.);
- Optimum concentration of approximately 55 g $^{235}U$/L (corresponding to a volume of approximately 14 liters);
- Full water reflection; and
- Isotopic content of 100 wt. % $^{235}U$.

This value has traditionally been used in the assessment of isolated Highly Enriched Uranium (HEU) units as a pessimistic but bounding case to generically consider all possible conditions within contaminated wastes.

As discussed above, the nature of SNM residues is such that it is not considered credible that a situation could arise in which all parameters are optimized and the presence of a minimum critical mass would result in a criticality. The reactivity of any system and hence the fissile mass that would be required for criticality is dependent on the combination of a number of parameters (e.g., concentration, moderating properties of the waste matrix, geometry, and reflection conditions).

## CRITICAL AND SUBCRITICAL LIMITS

Table A-1 outlines the subcritical and critical limits for $^{235}$U-water systems used in the safety assessment. It is acknowledged that there is potential to exhume or encounter hydro-carbon based liquids that could be more efficient moderators than water. However, due to the nature of the uranium residues and their associated waste matrix, the aqueous limits are considered conservative.

Table A-1 Single Parameter Limits for homogeneous $^{235}$U/water mixtures

| Parameter | Critical Limit (see Note 1) | Maximum Subcritical Limit (see Note 2) | Description / Restrictions |
|---|---|---|---|
| Mass | 820 g$^{235}$U | 760 g$^{235}$U | Any geometrical configuration, even when optimally moderated and fully reflected by water. Applies to all chemical forms (e.g., oxides as powders, metals, etc.). |
| Concentration | 11.8 g$^{235}$U/L | 11.6 g$^{235}$U/L | Unlimited volume of homogeneous solution in any chemical form (e.g., nitrate, oxalate, etc.), and in any geometry. |
| Volume | 6.1 L | 5.5 L | Homogeneous solution in any chemical form (e.g., nitrate, oxalate, etc.), at any concentration, fully reflected by water. |
| Geometry (∞ Cylinder Diameter) | 14.3 cm | 13.7 cm | Homogeneous solution in any chemical form (e.g., nitrate, oxalate, etc.), at any concentration and volume, and fully reflected by water. |
| Geometry (∞ Slab Thickness) | 4.9 cm | 4.4 cm | Homogeneous solution in any chemical form (e.g., nitrate, oxalate, etc.), at any concentration and volume, and fully reflected by water. |
| Geometry (∞ Slab Areal Concentration) | 390 g/ft$^2$ (0.42 g/cm$^2$) | 372 g/ft$^2$ (0.40 g/cm$^2$) | Homogeneous solution in any chemical form (e.g., nitrate, oxalate, etc.), any volume (i.e., any slab depth) and fully reflected by water. |

Source: Ref. 2 and Ref. 3

Notes:
1. Ref. 3, page III.B-2
2. Ref. 2, Table 1

Table A-2 outlines the single parameter critical limits for homogeneous U-water systems as a function of the U enrichment.

Table A-2 Critical Limits for homogeneous U/water mixtures as a function of U enrichment

| U Enrichment wt.% $^{235}$U/U | Spherical Critical Mass (g) | Spherical Critical Volume (L) | Critical ∞ Cylinder Diameter (cm) | Critical ∞ Slab Thickness (cm) |
|---|---|---|---|---|
| 3# | 3200 | 80.0 | 38.0 | 20.0 |
| 5# | 1950 | 37.0 | 28.0 | 14.0 |
| 30.3# | 990 | 11.0 | 19.0 | 7.4 |
| 100## | 820 | 6.1 | 14.3 | 4.9 |

Source: Ref. 3 and Ref. 4

Notes:
# Ref. 3, page III.B-2
## Ref. 4, Figures 14-17

Reference 19 presents the results of a broad and comprehensive set of calculations performed to compare the reactivity of various finite and infinite systems containing uranium. This calculation established a minimum critical infinite sea concentration for a $^{235}$U/soil mixture of 5.5 g$^{235}$U/L. Assuming a maximum safe fissile concentration of 4.0 g$^{235}$U/L provides a substantial subcritical margin of 0.15 g$^{235}$U/L. This margin is considered sufficiently large to also address any additional penalty that may be appropriate to account for validation of the materials modeled in the calculations used to establish the limit.